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FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 61400-1 has been prepared by IEC technical committee 88: Wind turbine generator systems.
This second edition cancels and replaces the first edition published in 1994.

The text of this standard is based on

FDIS	Report on voting
XXX/FDIS	XXX/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

Annexes A, B and C form an integral part of this standard.

Annex D is for information only.

INTRODUCTION

This International Standard outlines minimum safety requirements for wind turbine generator systems and is not intended for use as a complete design specification or instruction manual.

Any of the requirements of this standard may be waived if it can be suitably demonstrated that the safety of the system is not compromised. Nevertheless this waiver does not apply to clause 3.

Compliance with this standard does not relieve any person, organization, or corporation from the responsibility of observing other applicable regulations.

1 General

1.1 Scope

This part of IEC 61400 deals with safety philosophy, quality assurance and engineering integrity, and specifies requirements for the safety of Wind Turbine Generator Systems (WTGS), including design, installation, maintenance, and operation under specified environmental conditions. Its purpose is to provide the appropriate level of protection against damage from all hazards from these systems during their planned lifetime.

This standard is concerned with all subsystems of WTGS such as control and protection mechanisms, internal electrical systems, mechanical systems, support structures and the electrical interconnection equipment.

This standard applies to WTGS with swept area equal to or larger than 40 m^2.

This standard should be used together with the appropriate IEC/ISO standards identified in 2, 2.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 61400. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this part of IEC 61400 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60204-1: 1997, Electrical equipment of industrial machines – Part 1: General requirements

IEC 60364 (all parts) Electrical installations of buildings

IEC 364-5-54: 1997, Electrical installations of buildings – Part 5: Selection and erection of electrical equipment – Chapter 52: Wiring systems

IEC 60721-2-1: 1982, Classification of environmental conditions - Part 2: Environmental conditions appearing in nature. Temperature and humidity

IEC 61000-3-2: 1997, Electromagnetic compatibility (EMC) – Part 3: Limits – Section 2: Limits for harmonic current emissions (equipment input current 6 per phase)

IEC 61000-3-3: 1994, Electromagnetic compatibility (EMC) – Part 3: Limits – Section 3: Limitation of voltage fluctuations and flicker in low-voltage supply systems for equipment with rated current 16 A

IEC 61000-4-2: 1995, Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 2: Electrostatic discharge immunity test. Basic EMC publication

IEC 61000-4-3: 1995, Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 3: Radiated, radio-frequency, electromagnetic field immunity test

IEC 61000-4-4: 1995, Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 4: Electrical fast transient/burst immunity test. Basic EMC publication

IEC 61000-4-5: 1995, Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 5: Surge immunity test

IEC 61024-1: 1990, Protection of structures against lightning - Part 1: General principles

IEC 61310-1: 1995, Safety of machinery – Indication, marking and actuation – Part 1: Requirements for visual, auditory and tactile signals

IEC 61310-2: 1995, Safety of machinery – Indication, marking and actuation – Part 2: Requirements for marking

IEC 61312-1: 1995, Protection against lightning electromagnetic impulse – Part 1: general principles

ISO 2394: 1986, General principles on reliability for structures

ISO 9001: 1994, Quality systems - Model for quality assurance in design/development, production, installation and servicing

ISO 9002: 1994, Quality systems - Model for quality assurance in production , production, installation and servicing

ISO 9003: 1994, Quality systems - Model for quality assurance in final inspection and test

3 Terms and definitions

For the purpose of this International Standard, the following definitions apply:

3.1
annual average
mean value of a set of measured data of sufficient size and duration to serve as an estimate of the expected value of the quantity. The averaging time interval shall be a whole number of years to average out non-stationary effects such as seasonality

3.2
annual average wind speed
wind speed averaged according to the definition of annual average

3.3
auto-reclosing cycle
event with a time period, varying from approximately 0,01 s to a few seconds, during which a breaker released after a grid fault is automatically reclosed and the line is reconnected to the network

3.4
blocking (wind turbines)
use of a mechanical pin or other device (other than the ordinary mechanical brake) to prevent movement, for instance of the rotor shaft or yaw mechanism

3.5
brake (wind turbines)
device capable of reducing the rotor speed or stopping rotation

3.6
catastrophic failure (wind turbines)
disintegration or collapse of a component or structure, that results in loss of vital function which impairs safety

3.7
characteristic value (of a material property)
value having a prescribed probability of not being attained in a hypothetical unlimited test series

3.8
complex terrain
surrounding terrain that features significant variations in topography and terrain obstacles that may cause flow distortion

3.9
control system (wind turbines)
sub-system that receives information about the condition of the wind turbine and/or its environment and adjusts the turbine in order to maintain it within its operating limits

3.10
cut-in wind speed (V_{in})
lowest mean wind speed at hub height at which the wind turbine starts to produce power (see 3.24, hub height)

3.11
cut-out wind speed (V_{out})
highest mean wind speed at hub height at which the wind turbine is designed to produce power (see 3.24, hub height)

3.12
design limits
maximum or minimum values used in a design

3.13
dormant failure (also known as latent fault)
failure of a component or system which remains undetected during normal operation

3.14
downwind
in the direction of the main wind vector

3.15
electrical power network
particular installations, substations, lines or cables for the transmission and distribution of electricity

NOTE - The boundaries of the different parts of this network are defined by appropriate criteria, such as geographical situation, ownership, voltage, etc.

3.16
emergency shutdown (wind turbines)
rapid shutdown of the wind turbine triggered by a protection system or by manual intervention

3.17
environmental conditions
characteristics of the environment (altitude, temperature, humidity, etc.) which may affect the WTGS behaviour

3.18
external conditions (wind turbines)
factors affecting operation of a wind turbine, including the wind regime, the electrical network conditions, and other climatic factors (temperature, snow, ice, etc.)

3.19
extreme wind speed
highest average wind speed, averaged over t s, that is likely to be experienced within a specified time period of N years ("recurrence period": N years)

NOTE - In this standard recurrence periods of N = 50 years and N = 1 year and averaging time intervals of t = 3 s and t = 10 min are used. In popular language the less precise term survival wind speed is often used. In this standard, however, the turbine is designed using extreme wind speeds for design load cases.

3.20
fail-safe
design property of an item which prevents its failures from resulting in critical faults

3.21
gust
temporary change in the wind speed

NOTE - A gust may be characterised by its rise-time, its magnitude and its duration.

3.22
horizontal axis wind turbine
wind turbine whose rotor axis is substantially parallel to the wind flow

3.23
hub (wind turbines)
fixture for attaching the blades or blade assembly to the rotor shaft

3.24
hub height (wind turbines)
height of the centre of the swept area of the wind turbine rotor above the terrain surface. (see 3.55, swept area)

3.25
idling (wind turbines)
condition of a wind turbine that is rotating slowly and not producing power

3.26
inertial sub-range
frequency interval of the wind turbulence spectrum, where eddies - after attaining isotropy - undergo successive break-up with negligible energy dissipation

NOTE - At a typical 10 m/s wind speed, the inertial sub-range is roughly from 0,02 Hz to 2 kHz.

3.27
isolated operation
stable and temporary operation of a discrete part of a power system after network splitting

3.28
limit state
state of a structure and the loads acting upon it, beyond which the structure no longer satisfies the design requirement (ISO 2394)

NOTE - The purpose of design calculations (i.e. the design requirement for the limit state) is to keep the probability of a limit state being reached below a certain value prescribed for the type of structure in question (ISO 2394).

3.29
logarithmic wind shear law
see wind profile

3.30
maximum power (wind turbines)
highest level of net electrical power delivered by a wind turbine in normal operation

3.31
mean wind speed
statistical mean of the instantaneous value of the wind speed averaged over a given time period which can vary from a few seconds to many years

3.32
nacelle
housing which contains the drive-train and other elements on top of a horizontal axis wind turbine tower.

3.33
network connection point (wind turbines)
cable terminals of a single wind turbine or, for a wind power station, the connection point to the electrical bus of the site power collection system

3.34
normal shutdown (wind turbines)
shutdown in which all stages are under the control of the control system

3.35
operating limits
set of conditions defined by the WTGS designer that govern the activation of the control and protection system

3.36
parked wind turbine
depending on the construction of the wind turbine, parked refers to the turbine being either in a stand-still or an idling condition

3.37
power collection system (wind turbines)
electric connection system that collects the power from one or more wind turbines. It includes all electrical equipment connected between the WTGS terminals and the network connection point

3.38
power law for wind shear
see wind profile

3.39
power output
power delivered by a device in a specific form and for a specific purpose

NOTE (wind turbines) - The electric power delivered by a WTGS

3.40
protection system (wind turbine)
system which ensures that a WTGS remains within the design limits

3.41
rated power
quantity of power assigned, generally by a manufacturer, for a specified operating condition of a component, device or equipment

NOTE (wind turbines) - Maximum continuous electrical power output which a WTGS is designed to achieve under normal operating conditions.

3.42
rated wind speed (v_r)
specified wind speed at which a wind turbine's rated power is achieved

3.43
Rayleigh distribution
probability distribution function, see 3.66 (wind speed distribution)

3.44
reference wind speed (V_{ref})
basic parameter for wind speed used for defining WTGS classes. Other design related climatic parameters are derived from the reference wind speed and other basic WTGS class parameters (see 6)

NOTE - A turbine designed for a WTGS class with a reference wind speed V_{ref}, is designed to withstand climates for which the extreme 10 min average wind speed with a recurrence period of 50 years at turbine hub height is lower than or equal to V_{ref}.

3.45
resonance
phenomenon appearing in an oscillating system, in which the period of a forced oscillation is very close to that of free oscillation

3.46
rotationally sampled wind velocity
wind velocity experienced at a fixed point of the rotating wind turbine rotor

NOTE - The turbulence spectrum of a rotationally sampled wind velocity is distinctly different from the normal turbulence spectrum. While rotating, the blade cuts through a wind flow that varies in space. Therefore the resulting turbulence spectrum will contain sizeable amounts of variance at the frequency of rotation and harmonics of the same.

3.47
rotor speed (wind turbines)
rotational speed of a wind turbine rotor about its axis

3.48
roughness length
extrapolated height at which the mean wind speed becomes zero if the vertical wind profile is assumed to have a logarithmic variation with height

3.49
safe life
prescribed service life with a declared probability of catastrophic failure

3.50
scheduled maintenance
preventive maintenance carried out in accordance with an established time schedule

3.51
serviceability limit state
limit state which correspond with criteria governing function related normal use (ISO 2394)

3.52
standstill
condition of a WTGS that is stopped

3.53
support structure (wind turbines)
part of a wind turbine comprising the tower and foundation

3.54
survival wind speed
popular name for the maximum wind speed that a construction is designed to withstand

NOTE - In this standard, the expression is not used. Design conditions instead refer to extreme wind speed (see 3.19).

3.55
swept area
projected area perpendicular to the wind direction that a rotor will describe during one complete rotation

3.56
turbulence intensity
ratio of the wind speed standard deviation to the mean wind speed, determined from the same set of measured data samples of wind speed, and taken over a specified period of time

3.57
turbulence scale parameter
wave length where the non-dimensional, longitudinal power spectral density 0,05

NOTE - The wave length is thus defined as $\Lambda_1 = V_{hub}/f_0$, where $f_0 S_1(f_0)/\sigma_1^2 = 0{,}05$

3.58
ultimate limit state
limit states which generally correspond to maximum load carrying capacity (ISO 2394)

3.59
unscheduled maintenance
maintenance carried out, not in accordance with an established time schedule, but after reception of an indication regarding the state of an item

3.60
upwind
in the direction opposite to the main wind vector

3.61
vertical axis wind turbine
wind turbine whose rotor axis is vertical

3.62
Weibull distribution
probability distribution function, see 3.66 (wind speed distribution)

3.63
wind farm
see 3.64 (wind power station)

3.64
wind power station
group or groups of wind turbine generators, commonly called a wind farm

3.65
wind profile - wind shear law
mathematical expression for assumed wind speed variation with height above ground

NOTE - Commonly used profiles are the logarithmic profile (1) or the power law profile (2).

$$V(z) = V(z_r) \cdot \frac{\ln(z/z_0)}{\ln(z_r/z_0)} \tag{1}$$

$$V(z) = V(z_r) \cdot \left(\frac{z}{z_r}\right)^{a} \tag{2}$$

where

$V(z)$ is the wind speed at height z

z is the height above ground

z_r is a reference height above ground used for fitting the profile

z_o is the roughness length

α is the wind shear (or power law) exponent

3.66
wind speed distribution
probability distribution function, used to describe the distribution of wind speeds over an extended period of time

NOTE - Often used distribution functions are the Rayleigh, $P_R(V_o)$, and the Weibull, $P_W(V_o)$, functions.

$$P_R(V_0) = 1 - \exp\left[-\pi\left(V_0/2V_{ave}\right)^2\right]$$
$$P_w(V_0) = 1 - \exp\left[-\left(V_0/C\right)^k\right] \qquad (3)$$

$$\text{with } V_{ave} = \begin{cases} C\,\Gamma\left(1+\dfrac{1}{k}\right) \\ C\sqrt{\pi}/2, \text{ if } k=2 \end{cases} \qquad (4)$$

where

- $P(V_0)$ is the cumulative probability function, i.e. the probability that $V<V_0$
- V_0 is the wind speed (limit)
- V_{ave} is the average value of V
- C is the scale parameter of the Weibull function
- k is the shape parameter of the Weibull function
- Γ is the gamma function

Both C and k can be evaluated from real data. The Rayleigh function is identical to the Weibull function if k = 2 is chosen and C and V_{ave} satisfy the condition stated in equation (4) for k = 2.

The distribution functions express the cumulative probability that the wind speed is lower than V_0. Thus $(P(V_1)\text{-}P(V_2))$, if evaluated between the specified limits V_1 and V_2, will indicate the fraction of time that the wind speed is within these limits. Differentiating the distribution functions yields the corresponding probability density functions.

3.67
wind shear
variation of wind speed across a plane perpendicular to the wind direction

3.68
wind shear exponent
also commonly known as power law exponent, see 3.65, wind profile - wind shear law

3.69
wind speed
at a specified point in space the wind speed is the speed of motion of a minute amount of air surrounding the specified point

NOTE - The wind speed is also the magnitude of the local wind velocity (vector) (see 3.71, wind velocity).

3.70
wind turbine generator system (WTGS)
system which converts kinetic energy in the wind into electrical energy

3.71
wind velocity
vector pointing in the direction of motion of a minute amount of air surrounding the point of consideration, the magnitude of the vector being equal to the speed of motion of this air "parcel" (i.e. the local wind speed)

NOTE - The vector at any point is thus the time derivative of the position vector of the air "parcel" moving through the point.

3.72
WTGS electrical system
all electrical equipment internal to the WTGS, up to and including the WTGS terminals, including equipment for earthing, bonding and communications. Conductors local to the WTGS which are intended to provide an earth termination network specifically for the WTGS are included

3.73
WTGS terminals
point or points identified by the WTGS supplier at which the WTGS may be connected to the power collection system. This includes connection for the purposes of transferring energy and communications

3.74
yawing
rotation of the rotor axis about a vertical axis (for horizontal axis wind turbines only)

3.75
yaw misalignment
horizontal deviation of the wind turbine rotor axis from the wind direction

4 Symbols and abbreviated terms

4.1 Symbols and units

a	slope parameter for turbulence standard deviation model	[-]
C	scale parameter of the Weibull distribution function	[m/s]
Coh	coherency function	
D	rotor diameter	[m]
f	frequency	[s^{-1}]
f_d	design value for material strength	[-]
f_k	characteristic value for material strength	[-]
F_d	design value for loads	[-]
F_k	characteristic value for loads	[-]
I_{15}	characteristic value of hub-height turbulence intensity at a ten-minute average wind speed of 15 m/s	[-]
k	shape parameter of the Weibull distribution function	[-]
K	modified Bessel function	[-]
L	isotropic turbulence integral scale parameter	[m]
L_e	coherency scale parameter	[m]
L_k	velocity component integral scale parameter	[m]
n_i	counted number of fatigue cycles in load bin i	[-]
$N(.)$	is the number of cycles to failure as a function of the stress (or strain) indicated by the argument (i.e. the characteristic S-N curve)	[-]
N	recurrence period for extreme situations	[y]
p	survival probability	[-]
$P_R(V_0)$	Rayleigh probability distribution, i.e. the probability that $V<V_0$	[-]
$P_W(V_0)$	Weibull probability distribution	[-]
r	magnitude of separation vector projection	[m]
s_i	the stress (or strain) level associated with the counted number of cycles in bin i	[-]
$S_1(f)$	power spectral density function	[m^2/s^2]
S_k	single sided velocity component spectrum	[m^2/s^2]
T	gust characteristic time	[s]
t	time	[s]
V	wind speed	[m/s]
$V(z)$	wind speed at height z	[m/s]
V_{ave}	annual average wind speed at hub height	[m/s]
V_{cg}	extreme coherent gust magnitude over the whole rotor swept area	[m/s]
V_{eN}	expected extreme wind speed (averaged over three seconds), with a recurrence time interval of N years. V_{e1} and V_{e50} for 1 year and 50 years, respectively	[m/s]
V_{gustN}	largest gust magnitude with an expected recurrence period of N years.	[m/s]
V_{hub}	wind speed at hub height averaged over ten minutes	[m/s]
V_{in}	cut-in wind speed	[m/s]
V_0	limit wind speed in wind speed distribution model	[m/s]

V_{out}	cut-out wind speed	[m/s]
V_r	rated wind speed	[m/s]
V_{ref}	reference wind speed averaged over ten minutes	[m/s]
$V(y,z,t)$	longitudinal wind velocity component to describe transient horizontal wind shear	[m/s]
$V(z,t)$	longitudinal wind velocity component to describe transient variation for extreme gust and shear conditions	[m/s]
x, y, z	co-ordinate system used for the wind field description; along wind (longitudinal), across wind (lateral) and height respectively	[m]
z_{hub}	hub height of the wind turbine	[m]
z_r	reference height above ground	[m]
z_0	roughness length for the logarithmic wind profile	[m]
α	wind shear power law exponent	[-]
β	parameter for extreme direction change model	[-]
δ	coefficient of variation	[-]
Γ	gamma function	[-]
γ_f	partial safety factor for loads	[-]
γ_m	partial safety factor for materials	[-]
γ_n	partial safety factor for consequences of failure	[-]
$\theta(t)$	wind direction change transient	[°]
θ_{cg}	angle of maximum deviation from the direction of the average wind speed under gust conditions	[°]
θ_{eN}	extreme direction change with a recurrence period of N years	[°]
Λ_1	turbulence scale parameter defined as the wave length where the non-dimensional, longitudinal power spectral density, $fS_1(f)/\sigma_1^2$, is equal to 0,05	[m]
σ_1	hub-height longitudinal wind velocity standard deviation	[m/s]
σ_2	hub-height vertical wind velocity standard deviation	[m/s]
σ_k	k^{th} hub-height component wind velocity standard deviation (k = 1, 2, or 3)	[m/s]

4.2 Abbreviations

A	Abnormal (for partial safety factors)
ac	Alternating current
C	Serviceability constraint
dc	Direct current
DLC	Design load case
ECD	Extreme coherent gust with direction change
ECG	Extreme coherent gust
EDC	Extreme wind direction change
EOG	Extreme operating gust
EWM	Extreme wind speed model
EWS	Extreme wind shear
F	Fatigue
HAWT	Horizontal axis wind turbine
N	Normal and extreme (for partial safety factors)
NWP	Normal wind profile model
NTM	Normal turbulence model
S	Special IEC WTGS class
T	Transport and erection (for partial safety factors)
U	Ultimate
VAWT	Vertical axis wind turbine
WTGS	Wind turbine generator system(s)

5 Principal elements

5.1 General

The engineering and technical requirements to ensure the safety of the structural, mechanical, electrical and control systems of the WTGS are given in the following clauses. This specification of requirements applies to the design, manufacture, installation and maintenance of WTGS and the associated quality management process. In addition, safety procedures which have been established in the various technologies that are used in the installation, operation and maintenance of WTGS shall be followed.

5.2 Design methods

This standard requires the use of a structural dynamics model to predict design loads. This model shall be used to determine the loads over a range of wind speeds, using the turbulence conditions and other extreme wind conditions defined in 6, 6 and design situations defined in 7, 7. All relevant combinations of external conditions and design situations shall be analyzed. A minimum set of such combinations has been defined as load cases in this standard.

Data from full scale testing of a WTGS may be used to increase confidence in predicted design values and to verify structural dynamics models and design situations.

Verification of the adequacy of the design shall be made by calculation and/or by testing. If test results are used in this verification, the external conditions during the test shall be shown to reflect the characteristic values and design situations defined in this standard. The selection of test conditions, including the test loads, shall take account of the relevant safety factors.

5.3 Safety classes

A WTGS shall be designed according to one of the following two safety classes:

- a normal safety class which applies when a failure results in risk of personal injury or economic and social consequences;
- a special safety class which applies when the safety requirements are determined by local regulations and/or the safety requirements are agreed between the manufacturer and the customer.

Partial safety factors, for normal safety class WTGS, are specified in 7.6 of this standard.

Partial safety factors for special safety class WTGS shall be agreed between the manufacturer and the customer. A WTGS designed according to the special safety class is a WTGS class S turbine as defined in 6.2, **Error! Unknown switch argument.**.

5.4 Quality assurance

Quality assurance shall be an integral part of the design, procurement, manufacture, installation, operation and maintenance of the WTGS and all their components.

It is recommended that the quality system complies with the requirements of the ISO 9000 series.

5.5 Wind turbine markings

The following information shall be as a minimum, prominently and legibly displayed on the indelibly marked turbine nameplate:

- WTGS manufacturer and country

- model and serial number;
- production year;
- rated power;
- reference wind speed, V_{ref};
- hub height operating wind speed range, V_{in} - V_{out};
- operating ambient temperature range;
- IEC WTGS class (see table 1);
- rated voltage at the WTGS terminals;
- frequency at the WTGS terminals or frequency range in the case that the nominal variation is greater than 2 %.

6 External conditions

6.1 General

The external conditions described in this clause shall be considered in the design of a WTGS.

WTGS are subjected to environmental and electrical conditions which may affect their loading, durability and operation. To ensure the appropriate level of safety and reliability, the environmental, electrical and soil parameters shall be taken into account in the design and shall be explicitly stated in the design documentation.

The environmental conditions are further divided into wind conditions and other environmental conditions. The electrical conditions refer to the network conditions. Soil properties are relevant to the design of WTGS foundations.

Each type of external condition may be subdivided into a normal and an extreme external condition. The normal external conditions generally concern long-term structural loading and operating conditions, while the extreme external conditions represent the rare but potentially critical external design conditions. The design load cases shall consist of a combination of these external conditions with wind turbine operational modes.

Wind conditions are the primary external consideration for structural integrity. Other environmental conditions also affect design features such as control system function, durability, corrosion, etc.

The normal and extreme conditions which are to be considered in design according to WTGS classes are prescribed in the following subclauses.

6.2 WTGS classes

The external conditions to be considered in design are dependent on the intended site or site type for a WTGS installation. WTGS classes are defined in terms of wind speed and turbulence parameters. The intention of the classes is to cover most applications. The values of wind speed and turbulence parameters are intended to represent the characteristic values of many different sites and do not give a precise representation of any specific site, see 11, Assessment of external conditions. The goal is to achieve WTGS classification with clearly varying robustness governed by the wind speed and turbulence parameters. Table 1 specifies the basic parameters which define the WTGS classes.

In cases where a special design (e.g. special wind conditions or other external conditions or a special safety class) see 5.3, 5.3 is necessary, a further WTGS class, class S, is defined. The design values for the WTGS class S shall be chosen by the designer and specified in the design documentation. For such special designs, the values chosen for the design conditions shall reflect a more severe environment than anticipated for the use of the WTGS.

The particular external conditions of offshore installations require WTGS class S design.

Table 1 - Basic parameters for WTGS classes

WTGS Class		I	II	III	IV	S
V_{ref}	(m/s)	50	42,5	37,5	30	
V_{ave}	(m/s)	10	8,5	7,5	6	Values to be
A	I_{15} (-)	0,18	0,18	0,18	0,18	specified
	a (-)	2	2	2	2	by the

B	I_{15} (-)	0,16	0,16	0,16	0,16	designer
	a (-)	3	3	3	3	

where:

the values apply at hub height, and

A designates the category for higher turbulence characteristics,

B designates the category for lower turbulence characteristics,

I_{15} is the characteristic value of the turbulence intensity at 15 m/s,

a is the slope parameter to be used in equation (7).

In addition to these basic parameters, several important further parameters are required to specify completely the external conditions used in WTGS design. In the case of the WTGS classes I_A through IV_B, later referred to as standard WTGS classes, the values of these additional parameters are specified in 6.3, 6.4 and 6.5.

The design lifetime is to be at least 20 years.

For the WTGS class S the manufacturer shall in the design documentation describe the models used and values of essential design parameters. Where the models in 6 are adopted, statement of the values of the parameters will be sufficient. The design documentation of WTGS class S shall contain the information listed in annex A.

The abbreviations added in parentheses in the sub-clause headings in the remainder of this clause are used for describing the wind conditions for the design load cases defined in 7.4.

6.3 Wind conditions

A WTGS shall be designed to withstand safely the wind conditions defined by the selected WTGS class.

The design values of the wind conditions shall be clearly specified in the design documentation.

The wind regime for load and safety considerations is divided into the normal wind conditions which will occur frequently during normal operation of a WTGS, and the extreme wind conditions which are defined as having a 1 year or 50 year recurrence period.

In all cases the influence of an inclination of mean flow with respect to the horizontal plane of up to 8 degrees shall be considered. The flow inclination angle may be assumed to be invariant with height.

6.3.1 Normal wind conditions

6.3.1.1 Wind speed distribution

The wind speed distribution at the site is significant for the WTGS design because it determines the frequency of occurrence of the individual load conditions. In case of the standard WTGS classes, the mean value of the wind speed over a time period of 10 min shall be assumed to be Rayleigh distributed for the purposes of design load calculations. In this case, the probability distribution at hub height is given by:

$$P_R(V_{hub}) = 1 - \exp\left[-\pi\left(V_{hub} / 2V_{ave}\right)^2\right] \tag{5}$$

6.3.1.2 The normal wind profile model (NWP)

The wind profile, *V(z)*, denotes the average wind speed as a function of height, *z*, above the ground. In the case of standard WTGS classes, the normal wind speed profile shall be assumed to be given by the power law:

$$V(z) = V_{hub} \left(z / z_{hub} \right)^{\alpha} \tag{6}$$

The power law exponent, α, shall be assumed to be 0,2.

The assumed wind profile is used to define the average vertical wind shear across the rotor swept area.

6.3.1.3 Normal turbulence model (NTM)

The expression "wind turbulence" denotes stochastic variations in the wind velocity from the 10 min average. The turbulence model shall include the effects of varying wind speed, varying direction, and rotational sampling. For the standard WTGS classes, the power spectral densities of the random wind velocity vector field, whether used explicitly in the model or not, shall satisfy the following requirements:

a) The characteristic value of the standard deviation of the longitudinal wind velocity component shall be given by[1]):

$$\sigma_1 = I_{15} \left(15 \text{ m/s} + a V_{hub} \right) \big/ (a+1) \tag{7}$$

Values for I_{15} and *a* are given in table 1. The characteristic values of the standard deviation, σ_1, and of the turbulence intensity, σ_1/V_{hub}, are shown below in figure 1 as a function of wind speed for the specified values of I_{15} and *a*.

The standard deviation is assumed to be invariant with height.

1) To perform the calculations of load cases in addition to those specified in table 2, it may be appropriate to use different percentile values. Such percentile values shall be determined by adding a value to equation 7 given by:

$$\Delta\sigma_1 = (x-1)(2 \text{ m/s}) I_{15}$$

where *x* is determined from the normal probability distribution function. For example, *x* = 1,64 for a 95^{th} percentile value.

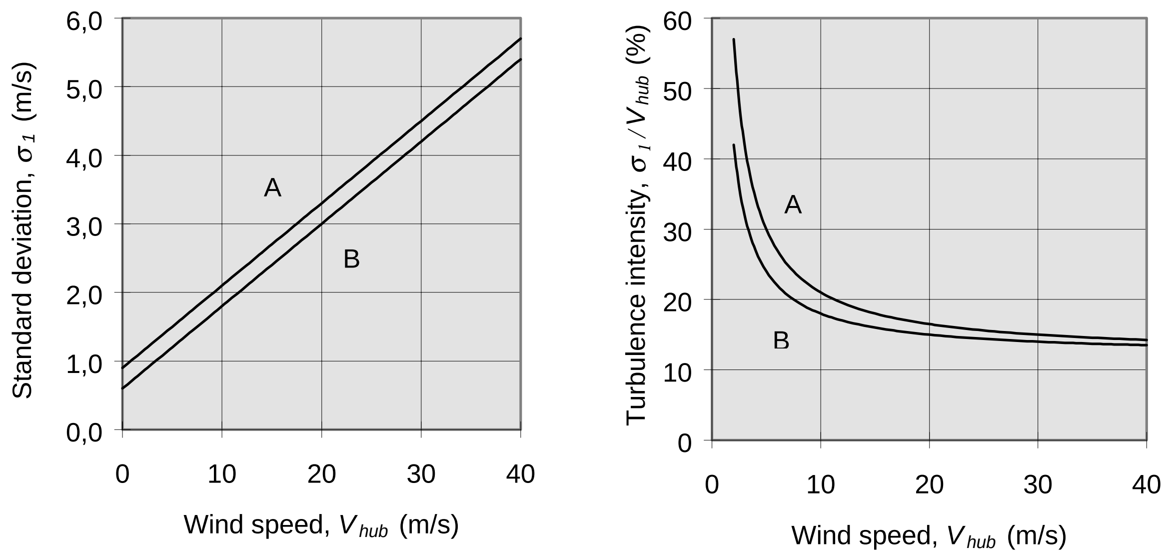


Figure 1 - Characteristic wind turbulence

b) Towards the high frequency end of the inertial subrange the power spectral density of the longitudinal component of the turbulence, $S_1(f)$, shall asymptotically approach the form:

$$S_1(f) = 0{,}05(\sigma_1)^2 (\Lambda_1 / V_{hub})^{-2/3} f^{-5/3} \qquad (8)$$

The turbulence scale parameter, Λ_1,shall be given by:

$$\Lambda_1 = \begin{cases} 0{,}7 z_{hub} & \text{for} \quad z_{hub} < 30\,\text{m} \\ 21\text{m} & \text{for} \quad z_{hub} \geq 30\,\text{m} \end{cases} \qquad (9)$$

Specifications for stochastic turbulence models which satisfy these requirements are given in annex B. In annex C a simplified deterministic model which is based on a stochastic description of the turbulence is given. This deterministic model may be used when it can be demonstrated that the turbine blade response to rotationally sampled wind velocity is sufficiently well damped. Guidance for this validation is also given in annex C.

6.3.2 Extreme wind conditions

The extreme wind conditions are used to determine extreme wind loads on WTGS. These conditions include peak wind speeds due to storms and rapid changes in wind speed and direction. These extreme conditions include the potential effects of wind turbulence so that only the deterministic effects need to be considered in the design calculations.

6.3.2.1 Extreme wind speed model (EWM)

The 50 year extreme wind speed V_{e50} and the one year extreme wind speed V_{e1} shall be based on the reference wind speed V_{ref}. For WTGS designs in the standard WTGS classes, V_{e50} and V_{e1} shall be computed as a function of height z using the following equations:

$$V_{e50}(z) = 1{,}4\; V_{ref} \left(z/z_{hub}\right)^{0{,}11} \qquad (10)$$

$$V_{e1}(z) = 0{,}75\ V_{e50}(z) \qquad (11)$$

where z_{hub} is the hub height [2]).

Short-term deviations from the mean wind direction of ± 15 degrees shall be assumed.

6.3.2.2 Extreme operating gust (EOG)

The hub height gust magnitude V_{gustN} for a recurrence period of N years shall be given for the standard WTGS classes by the following relationship:

$$V_{gustN} = \beta\left(\frac{\sigma_1}{1+0.1(\frac{D}{\Lambda_1})}\right) \qquad (12)$$

where

σ_1 is the standard deviation, according to equation (7);

Λ_1 is the turbulence scale parameter, according to equation (9);

D is the rotor diameter;

β = 4,8 for N = 1; and

β = 6,4 for N = 50.

The wind speed shall be defined for a recurrence period of N years by the equation:

$$V(z,t) = \begin{cases} V(z) - 0{,}37 V_{gustN}\ \sin(3\pi t / T)(1 - \cos(2\pi t / T)) & \text{for} \quad 0 \le t \le T \\ V(z) & \text{for} \quad t < 0 \text{ and } t > T \end{cases} \qquad (13)$$

where

$V(z)$ is defined in equation (6);

T = 10,5 s for N = 1; and

T = 14,0 s for N = 50.

As an example, the extreme operating gust with a recurrence period of one year, turbulence category A and V_{hub} = 25 m/s is shown in figure 2:

2) Note - Local structural engineering codes may prescribe a variation of wind speed or dynamic pressure with height which is slightly different from that which results from the relation given above.

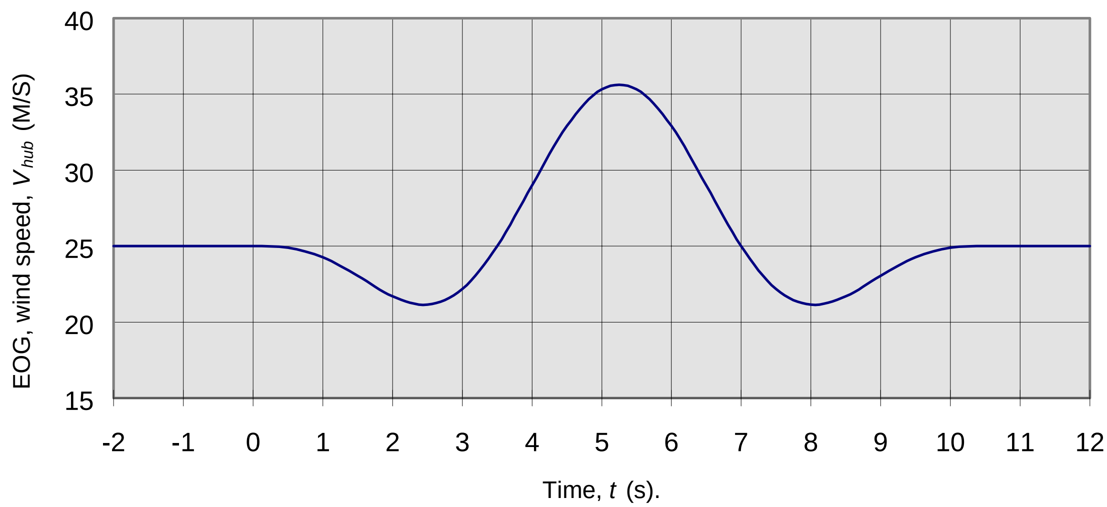


Figure 2 - Example of extreme operating gust (N = 1, category A, V_{hub} = 25 m/s)

The parameter values for both recurrence periods were selected to give the same maximum rise rate.

6.3.2.3 Extreme direction change (EDC)

The extreme direction change magnitude, θ_{eN}, for a recurrence period of N years shall be calculated using the following relationship:

$$\theta_{eN}(t) = \pm\beta \arctan\left(\frac{\sigma_1}{V_{hub}\left(1 + 0{,}1\left(\frac{D}{\Lambda_1}\right)\right)}\right) \tag{14}$$

where

θ_{eN} is limited to the interval $\pm 180°$;

Λ_1 is the turbulence scale parameter, according to equation (9);

D is the rotor diameter;

β = 4,8 for N = 1; and

β = 6,4 for N = 50.

The extreme direction change transient for a recurrence period of N years, $\theta_N(t)$,shall be given by:

$$\theta_N(t) = \begin{cases} 0 & \text{for} \quad t < 0 \\ 0{,}5\,\theta_{eN}\left(1 - \cos(\pi t / T)\right) & \text{for} \quad 0 \le t \le T \\ \theta_{eN} & \text{for} \quad t > T \end{cases} \tag{15}$$

where T = 6 s is the duration of the extreme direction change transient. The sign shall be chosen so that the worst transient loading occurs. At the end of the direction change transient the direction is assumed to remain unchanged. The wind speed is assumed to follow the normal wind profile of 6.3.1.2, 6.3.1.2.

As an example, the extreme direction change with a recurrence period of 50 years, turbulence category A and V_{hub} = 25 m/s is shown in figure 3.

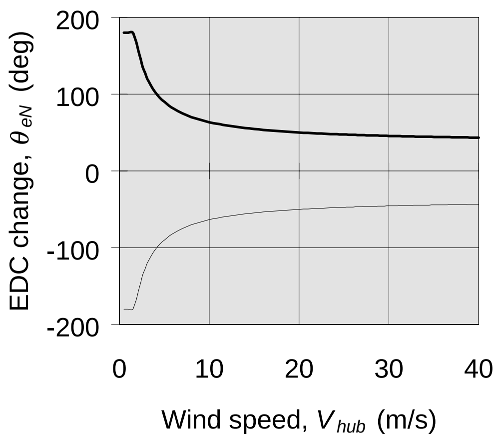


Figure 3 - Example of extreme direction change magnitude (*N* = 50, category A, *D* = 42 m, z_{hub} = 30 m)

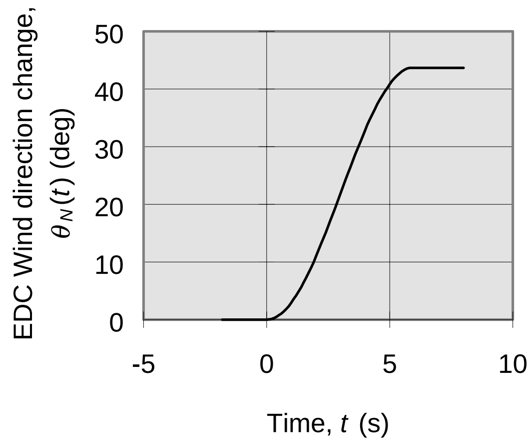


Figure 4 - Example of extreme direction change (*N* = 50, category A, V_{hub} = 25 m/s)

6.3.2.4 Extreme coherent gust (ECG)

For WTGS designs for the standard WTGS classes, an extreme coherent gust with a magnitude of:

$$V_{cg} = 15 \text{ m/s}$$

shall be assumed. The wind speed shall be defined by the relations:

$$V(z,t) = \begin{cases} V(z) & \text{for} \quad t < 0 \\ V(z) + 0{,}5V_{cg}\left(1 - \cos(\pi\, t/T)\right) & \text{for} \quad 0 \le t \le T \\ V(z) + V_{cg} & \text{for} \quad t > T \end{cases} \tag{16}$$

where T = 10 s is the rise time and V(z) the wind speed given in 6.3.1.2, 6.3.1.2. The normal wind profile model of wind speed as specified in equation (6) shall be used. The extreme coherent gust is illustrated in figure 5 for V_{hub}=25 m/s.

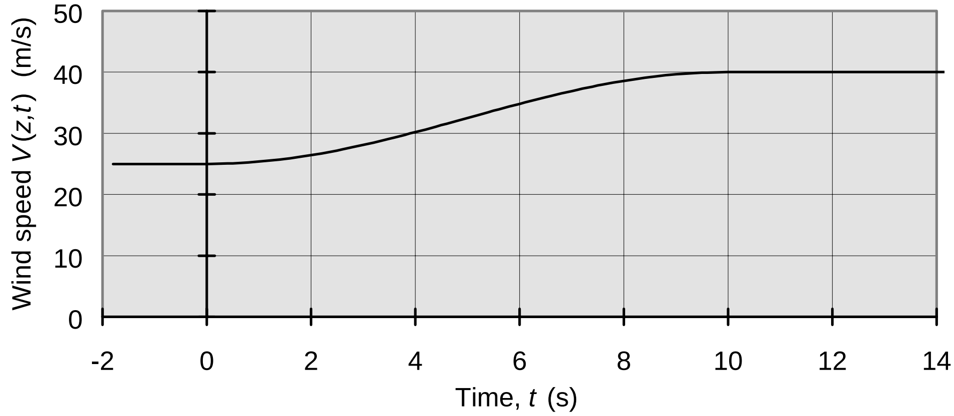


Figure 5 - Extreme coherent gust (V_{hub} = 25 m/s) (ECG)

6.3.2.5 Extreme coherent gust with direction change (ECD)

In this case, the rise in wind speed (described by ECG, see figure 5) shall be assumed to occur simultaneously with the direction change θ_{cg}, where θ_{cg} is defined by the relations:

$$\theta_{cg}(V_{hub}) = \begin{cases} 180^\circ & \text{for} \quad V_{hub} < 4\ \text{m/s} \\ \dfrac{720^\circ\ \text{m/s}}{V_{hub}} & \text{for} \quad 4\ \text{m/s} \le V_{hub} \le V_{ref} \end{cases} \tag{17}$$

The direction change, θ_{cg}, as a function of V_{hub} and as a function of time for V_{hub} = 25 m/s is shown in figures 6 and 7, respectively.

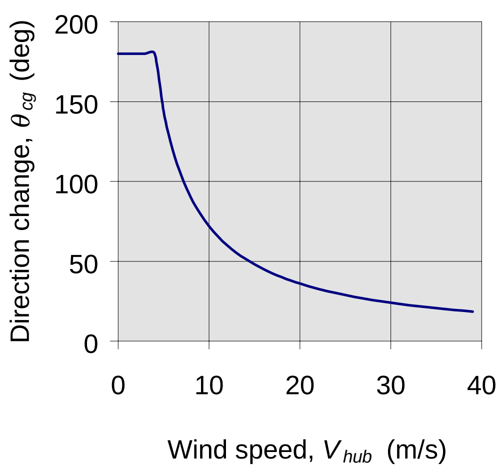


Figure 6 - The direction change for ECD

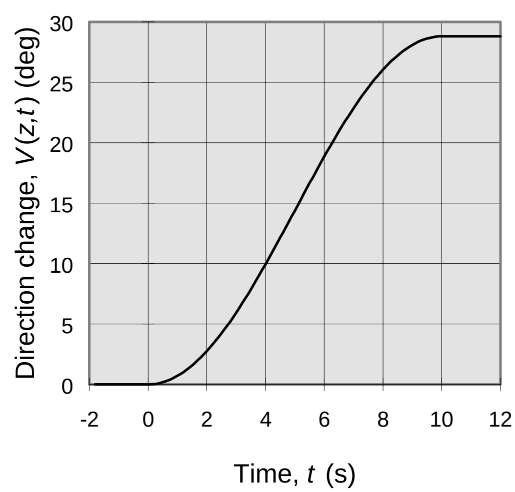


Figure 7 - Time development of direction change for V_{hub} = 25 m/s

The simultaneous direction change is then given by:

$$\theta(t) = \begin{cases} 0^0 & for \quad t < 0 \\ \pm 0{,}5\theta_{cg}(1 - \cos(\pi t / T)) & for \quad 0 \le t \le T \\ \pm \theta_{cg} & for \quad t > T \end{cases} \tag{18}$$

where T = 10 s is the rise time. The normal wind profile model as specified in equation (6) shall be used.

6.3.2.6 Extreme wind shear (EWS)

The extreme wind shear with a recurrence period of 50 years shall be accounted for using the following two wind speed transients:

– for transient vertical shear:

$$V(z,t) = \begin{cases} V_{hub}\left(\dfrac{z}{z_{hub}}\right)^{\alpha} + \left(\dfrac{z - z_{hub}}{D}\right)\left(2{,}5 + 0{,}2\,\beta\sigma_1\left(\dfrac{D}{\Lambda_1}\right)^{1/4}\right)\left(1 - \cos\left(\dfrac{2\pi t}{T}\right)\right) & \text{for} \quad 0 \le t \le T \\ V_{hub}\left(\dfrac{z}{z_{hub}}\right)^{\alpha} & \text{for} \quad t < 0 \; and \; t > T \end{cases} \tag{19}$$

– for transient horizontal shear:

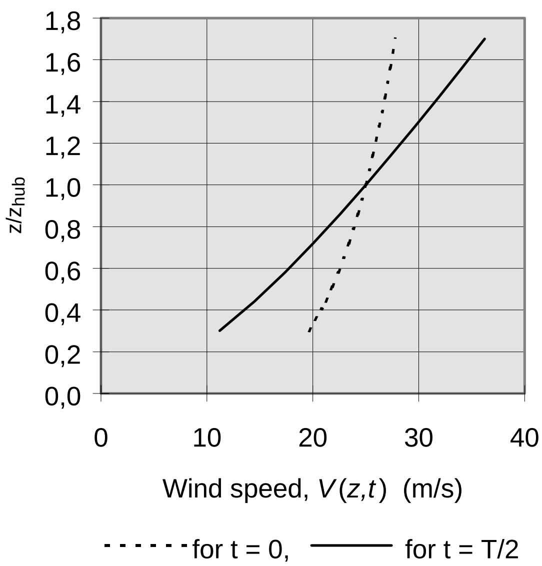
$$V(y,z,t) = \begin{cases} V_{hub}\left(\dfrac{z}{z_{hub}}\right)^{\alpha} + \left(\dfrac{y}{D}\right)\left(2{,}5 + 0{,}2\,\beta\sigma_1\left(\dfrac{D}{\Lambda_1}\right)^{1/4}\right)\left(1 - \cos\left(\dfrac{2\pi t}{T}\right)\right) & \text{for} \quad 0 \le t \le T \\ V_{hub}\left(\dfrac{z}{z_{hub}}\right)^{\alpha} & \text{for} \quad t < 0 \; and \; t > T \end{cases} \tag{20}$$

where

α = 0,2; β = 6,4; T = 12 s;

Λ_1 is the turbulence scale parameter, according to equation (9); and

D is the rotor diameter.



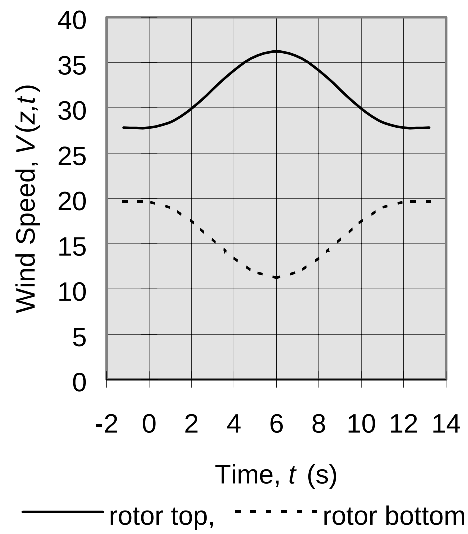


Figure 8 - Extreme vertical wind shear, wind profile before onset (*t* = 0, dashed line) and at maximum shear (*t* = 6 s, full line) (*N* = 50, turbulence category A, z_{hub} = 30 m, V_{hub} = 25 m/s, *D* = 42 m).

Figure 9 - Wind speeds at rotor top and bottom respectively illustrate the time development of wind shear (assumptions as in figure 8).

The sign for the horizontal wind shear transient shall be chosen so that the worst transient loading occurs. The two extreme wind shears are considered independently from each other and are therefore not applied simultaneously. As an example the 50 year extreme vertical wind shear is illustrated in figure 8 which shows the wind profiles before onset of the extreme event (*t* = 0 s) and at maximum shear (*t* = 6 s) and figure 9 shows the wind speeds at the top and the bottom of the rotor to illustrate the time development of the shear. In both figures, turbulence category A and V_{hub} = 25 m/s, z_{hub} = 30 m, rotor diameter *D* = 42 m are assumed.

6.4 Other environmental conditions

Environmental (climatic) conditions other than wind can affect the integrity and safety of the WTGS, by thermal, photochemical, corrosive, mechanical, electrical or other physical action. Moreover, combinations of the climatic parameters given may increase their effect.

At least the following other environmental conditions shall be taken into account and the action taken stated in the design documentation:

- temperature;
- humidity;
- air density;
- solar radiation;
- rain, hail, snow and ice;
- chemically active substances;
- mechanically active particles;
- lightning;
- earthquakes;
- salinity.

An offshore environment requires special additional consideration.

The climatic conditions for the design shall be defined in terms of representative values or by the limits of the variable conditions. The probability of simultaneous occurrence of the climatic conditions shall be taken into account when the design values are selected.

Variations in the climatic conditions within the normal limits which correspond to a one year return period shall not interfere with the designed normal operation of a WTGS.

Unless correlation exists, other extreme environmental conditions according to 6.4.1, 6.4.2, shall be combined with the normal wind conditions according to 6.3.1, 6.3.1.

6.4.1 Other normal environmental conditions

The other normal environmental condition values which shall be taken into account are:

- normal system operation ambient temperature range of -10 °C to +40 °C;
- relative humidity of up to 95 %;
- atmospheric content equivalent to that of a non-polluted inland atmosphere (see IEC 60721-2-1);
- solar radiation intensity of 1.000 W/m^2;
- air density of 1,225 kg/m^3.

When additional external condition parameters are specified by the designer, these parameters and their values shall be stated in the design documentation and shall conform to the requirements of IEC 60721-2-1.

6.4.2 Other extreme environmental conditions

Other extreme environmental conditions which shall be considered for WTGS design are temperature, lightning, ice and earthquakes.

6.4.2.1 Temperature

The design values for the extreme temperature range shall be at least -20 °C to +50 °C for the standard WTGS classes.

6.4.2.2 Lightning

The provisions of lightning protection required in 10.6, 10.6, may be considered as adequate for wind turbines in the standard WTGS classes.

6.4.2.3 Ice

No minimum ice requirements are given for the standard WTGS classes.

6.4.2.4 Earthquakes

No minimum earthquake requirements are given for the standard WTGS classes.

6.5 Electrical power network conditions

The normal conditions at the WTGS terminals to be considered in design are listed below.

Normal electrical power network conditions apply when the following parameters fall within the ranges stated below.

- Voltage

Nominal value ± 10%

– Frequency

Nominal value ± 2%

– Voltage imbalance

The ratio of the negative-sequence component of voltage to the positive-sequence component will not exceed 2 %.

– Outages

Electrical network outages shall be assumed to occur 20 times per year. The maximum outage duration for which the turbine shall be designed shall be at least one week.

7 Structural design

7.1 General

Wind turbine structural design shall be based on verification of the structural integrity of the load-carrying components. The ultimate and fatigue strength of structural members shall be verified by calculations and/or tests to demonstrate the structural integrity of a WTGS with the appropriate safety level.

The structural analysis shall be based on ISO 2394.

An acceptable safety level shall be ascertained and verified by calculations and/or tests to demonstrate that the design loading will not exceed the relevant design resistance.

Calculations shall be performed using appropriate methods. Descriptions of the calculation methods shall be provided in the design documentation. The descriptions shall include evidence of the validity of the calculation methods or references to suitable verification studies. The load level in any test shall reflect the factors of safety in the corresponding calculation.

7.2 Design methodology

It shall be verified that limit states are not exceeded for the wind turbine design. Model testing and prototype tests may also be used as a substitute for calculation to verify the structural design, as specified in ISO 2394.[3])

7.3 Loads

Loads described in 7.3.1, 7.3.1, through 7.3.4, 7.3.4, shall be considered for the design calculations.

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3) ISO 2394 defines the ultimate and serviceability limit states as follows: A state of a structure and the loads acting upon it, beyond which the structure no longer satisfies the design requirement. The purpose of design calculations is to keep the probability of a limit state being reached below a certain value prescribed for the type of structure in question.

For example, *Ultimate limit states* correspond to:

- loss of equilibrium of the structure, or of a part of the structure, considered as a rigid body (e.g. overturning);
- rupture of critical sections of the structure caused by exceeding the ultimate strength (in some cases reduced by repeated loading) or the ultimate deformation of the material;
- transformation of the structure into a mechanism (collapse), loss of stability (buckling, etc.).

For example,*Serviceability limit states* correspond to:

- deformations which affect the efficient use or appearance of structural or non-structural elements;
- excessive vibrations producing discomfort or affecting non-structural elements or equipment (especially if resonance occurs);
- local damage (including cracking) which reduces the durability of a structure or affects the efficiency or appearance of structural or non-structural elements.

To control serviceability limit states by design it is often necessary to use one or more constraints which describe acceptable deformations, accelerations, crack widths, etc.

7.3.1 Inertial and gravitational loads

Inertial and gravitational loads are static and dynamic loads acting on WTGS resulting from vibration, rotation, gravity and seismic activity.

7.3.2 Aerodynamic loads

Aerodynamic loads are static and dynamic loads which are caused by the airflow and its interaction with the stationary and moving parts of WTGS.

The airflow is dependent upon the rotational speed of the rotor, the average wind speed across the rotor plane, the turbulence, the density of the air, and the aerodynamic shapes of the wind turbine components and their interactive effects, including aeroelastic effects.

7.3.3 Operational loads

Operational loads result from the operation and control of WTGS. They are identified as being in several categories. These are the control of rotor speed such as torque control by pitching of blades or other aerodynamic devices. They include drive train mechanical braking and transient loads, caused by rotor stopping and starting, generator connection and disconnection and yawing loads.

7.3.4 Other loads

Other loads such as wave loads, wake loads, impact loads, ice loads, etc. may occur and shall be included where appropriate, see 11, Assessment of external conditions.

7.4 Design situations and load cases

This sub-clause describes the construction of design load cases of WTGS and specifies a minimum number to be considered.

For design purposes, the life of a WTGS can be represented by a set of design situations covering the most significant conditions which the WTGS may experience.

The load cases shall be determined from the combination of specific assembly, erection, maintenance, and operational modes or design situations with the external conditions. All relevant load cases with a reasonable probability of occurrence must be considered, together with the behaviour of the control and protection system.

Generally the design load cases used to determine the structural integrity of a WTGS may be calculated from the following combinations:

- normal design situations and normal external conditions;
- normal design situations and extreme external conditions;
- fault design situations and appropriate external conditions;
- transportation, installation and maintenance design situations and the appropriate external conditions.

If any correlation exists between an extreme external condition and a fault situation, a realistic combination of the two shall be considered as a design load case.

Within each design situation several design load cases shall be considered to verify the structural integrity of WTGS components. As a minimum the design load cases in table 2 shall be considered. In that table the design load cases are specified for each design situation by the description of the wind, electrical and other external conditions.

Other design load cases relevant for safety shall be considered, if required by the specific WTGS design.

For each design situation, the appropriate type of analysis is stated by “F” and “U” in table 2. F refers to analysis of fatigue loads, to be used in the assessment of fatigue strength. U refers to the analysis of ultimate loads such as analysis of exceeding the maximum material strength, analysis of tip deflection, and stability analysis.

The design situations indicated with U, are classified as normal (N), abnormal (A), or transport and erection (T). Normal design situations are expected to occur frequently within the lifetime of a turbine. The turbine is in a normal state or may have experienced minor faults or abnormalities. Abnormal design situations are less likely to occur. They usually correspond to design situations with more severe faults like protection system faults. The type of design situation, N, A, or T, determines the partial safety factor γ_f to be applied to the ultimate loads. These factors are given in tables 3 and 4 in 7.6, 7.6.

When a wind speed range is indicated in table 2, wind speeds leading to the most adverse condition for WTGS design shall be considered. The range may be divided into a number of bins; an appropriate fraction of the WTGS life shall be allocated to each bin. In the definition of the design load cases reference is made to the wind conditions described in 6, 6.

Table 2 - Design load cases

Design situation	DLC	Wind condition[4]		Other conditions	Type of analysis	Partial safety factors
1) Power production	1.1	NTM	$V_{hub} = V_r$ or V_{out}		U	N
	1.2	NTM	$V_{in} < V_{hub} < V_{out}$		F	*
	1.3	ECD	$V_{hub} = V_r$		U	N
	1.4	NWP	$V_{hub} = V_r$ or V_{out}	External electrical fault	U	N
	1.5	EOG_1	$V_{hub} = V_r$ or V_{out}	Loss of electrical connection	U	N
	1.6	EOG_{50}	$V_{hub} = V_r$ or V_{out}		U	N
	1.7	EWS	$V_{hub} = V_r$ or V_{out}		U	N
	1.8	EDC_{50}	$V_{hub} = V_r$ or V_{out}		U	N
	1.9	ECG	$V_{hub} = V_r$		U	N
2) Power production plus occurrence of fault	2.1	NWP	$V_{hub} = V_r$ or V_{out}	Control system fault	U	N
	2.2	NWP	$V_{hub} = V_r$ or V_{out}	Protection system or preceding internal electrical fault	U	A
	2.3	NTM	$V_{in} < V_{hub} < V_{out}$	Control or protection system fault	F	*
3) Start up	3.1	NWP	$V_{in} < V_{hub} < V_{out}$		F	*
	3.2	EOG_1	$V_{hub} = V_{in}$, V_r or V_{out}		U	N
	3.3	EDC_1	$V_{hub} = V_{in}$, V_r or V_{out}		U	N
4) Normal shut down	4.1	NWP	$V_{in} < V_{hub} < V_{out}$		F	*
	4.2	EOG_1	$V_{hub} = V_r$ or V_{out}		U	N
5) Emergency shut down	5.1	NWP	$V_{hub} = V_r$ or V_{out}		U	N
6) Parked (standing still or idling)	6.1	EWM	$V_{hub} = V_{e50}$	Possible loss of electrical power network	U	N
	6.2	NTM	$V_{hub} < 0.7\ V_{ref}$		F	*
7) Parked and fault conditions	7.1	EWM	$V_{hub} = V_{e1}$		U	A
8) Transport, assembly, maintenance and repair	8.1	To be stated by the manufacturer			U	T

4) If no cut-out wind speed V_{out} is defined, the value of V_{ref} should be used.

DLC	Design load case
ECD	Extreme coherent gust with direction change (see 6.3.2)
ECG	Extreme coherent gust (see 6.3.2)
EDC	Extreme direction change (see 6.3.2)
EOG	Extreme operating gust (see 6.3.2)
EWM	Extreme wind speed model (see 6.3.2)
EWS	Extreme wind shear (see 6.3.2)
Subscript	Recurrence period in years
NTM	Normal turbulence model (see 6.3.1)
NWP	Normal wind profile model (see 6.3.1)
F	Fatigue
U	Ultimate
N	Normal and extreme
A	Abnormal
T	Transport and erection
*	Partial safety factor for fatigue (see 7.6.3)

7.4.1 Power production (DLC 1.1 - 1.9)

In this design situation, a WTGS is running and connected to the electric load. The assumed WTGS configuration shall take into account rotor imbalance. The maximum mass and aerodynamic imbalances (e.g. blade pitch and twist deviations) specified for rotor manufacture shall be used in the design calculations.

In addition, deviations from theoretical optimum operating situations such as yaw misalignment and control system tracking errors shall be taken into account in the analyses of operational loads.

The worst combination of conditions shall be assumed in the calculation, e.g. direction change with characteristic yaw misalignment (DLC 1.8) or gust with loss of electrical connection (DLC 1.5).

Design load cases (DLC) 1.1 and 1.2 embody the requirements for loads resulting from atmospheric turbulence. DLC 1.3 and 1.6 - 1.9 specify transient cases which have been selected as potentially critical events in the life of a WTGS. In DLC 1.4 and 1.5 transitional events due to external faults and loss of electrical load are considered.

7.4.2 Power production plus occurrence of fault (DLC 2.1 - 2.3)

Any fault in the control or protection systems, or internal fault in the electrical system, significant for WTGS loading (such as generator short circuit), shall be assumed to occur during power production. For DLC 2.1 the occurrence of a fault in the control system which is considered a normal event shall be analysed. For DLC 2.2 the occurrence of faults in the protection or internal electrical systems which are considered to be rare events shall be analysed. If a fault does not cause an immediate shutdown and the consequent loading can lead to significant fatigue damage, the likely duration of this situation shall be evaluated in DLC 2.3.

7.4.3 Start up (DLC 3.1 - 3.3)

This design situation includes all the events resulting in loads on a WTGS during the transients from any stand still or idling situation to power production.

7.4.4 Normal shut down (DLC 4.1 - 4.2)

This design situation includes all the events resulting in loads on a WTGS during normal transient situations from a power production situation to a stand still or idling condition.

7.4.5 Emergency shut down (DLC 5.1)

Loads arising from emergency shut down shall be considered.

7.4.6 Parked (stand-still or idling) (DLC 6.1 - 6.2)

The rotor of a parked wind turbine which may be either in a stand-still or idling condition shall be considered with the extreme wind speed condition. If significant fatigue damage can occur to some components (e.g. from weight of idling blades), the expected number of hours of non-power production time at each appropriate wind speed shall also be considered. The effects of the loss of the electrical power network on a parked wind turbine shall be taken into account.

7.4.7 Parked plus fault conditions (DLC 7.1)

Deviations from the normal behaviour of a parked WTGS, resulting from faults on the electrical network or in the WTGS, shall require analysis. If any fault other than a loss of electrical power network produces deviations from the normal behaviour of the WTGS in parked situations, the possible consequences shall be the subject of analysis. The fault condition shall be combined with the extreme wind speed model (EWM) and a recurrence period of one year.

7.4.8 Transport, assembly, maintenance and repair (DLC 8.1)

The manufacturer shall state all the wind conditions and design situations assumed for transport, assembly, maintenance and repair of a WTGS. The maximum allowed wind conditions shall be considered in the design if they can produce significant loading on the WTGS.

7.5 Load calculations

Loads as described in 7.3.1 through 7.3.4 shall be taken into account for each design load case. Where relevant, the following shall also be taken into account:

– wind field perturbations due to the WTGS itself (wake induced velocities, tower shadow etc.);
– the influence of three dimensional flow on the blade aerodynamic characteristics (e.g., three dimensional stall and aerodynamic tip loss);
– unsteady aerodynamic effects;
– structural dynamics and the coupling of vibrational modes;
– aeroelastic effects;
– the behaviour of the control and protection system of the WTGS.

7.6 Ultimate limit state analysis

7.6.1 Method

The partial safety factors are dependent on the uncertainties and variabilities in loads and materials, the uncertainties in the analysis methods, and the importance of structural components with respect to the consequences of failure.

7.6.1.1 Partial safety factors

To assure safe design values for loads and materials, the uncertainties and variabilities in loads and materials are covered by partial safety factors for loads and materials defined in (21) and (22).

$$F_d = \gamma_f F_k \tag{21}$$

where

F_d are the design values for loads;

γ_f are the partial safety factors for loads; and

F_k are the characteristic values for loads. In this standard the alternative term “representative value” is used in some cases, where a characteristic value is not easily evaluated statistically.

$$f_d = \frac{1}{\gamma_m} f_k \tag{22}$$

where

f_d are the design values for materials;

γ_m are the partial safety factors for materials; and

f_k are the characteristic values of material properties.

The partial safety factors for loads used in this standard are meant to take account of:

– the possibility of unfavourable deviations of the load from the characteristic value
– uncertainties in the loading model

The partial safety factors for materials used in this standard are meant to take account of:

– the possibility of unfavourable deviations of the strength of material from the characteristic value
– possible inaccurate assessment of the resistance of sections or load-carrying capacity of parts of the structure
– uncertainties in the geometrical parameters
– uncertainties in the relation between the material properties in the structure and those measured by tests on control specimens, i.e. uncertainty in the conversion.

These different uncertainties are sometimes accounted for by means of individual partial safety factors but in this standard as in most others, the load related factors are combined into one factor γ_f and the material related factors into one factor γ_m. The consequences of failure factor, γ_n, is introduced to distinguish between:

Component class 1: used for "fail-safe" structural components whose failure does not result in the failure of a major part of a WTGS;

Component class 2: used for "non fail-safe" structural components whose failures lead rapidly to the failure of a major part of a WTGS.

For the ultimate limit state analysis of the WTGS, the following four types of analysis shall be performed where relevant:

– analysis of ultimate strength (see 7.6.2);
– analysis of fatigue failure (see 7.6.3);
– stability analysis (buckling, etc.) (see 7.6.4);

– critical deflection analysis (mechanical interference between blade and tower, etc.) (see 7.6.5).

The general equation for non-exceedance of the ultimate limit state is:

$$\gamma_n \cdot S\left(F_d\right) \leq R\left(f_d\right) \tag{23}$$

Each type of analysis requires a different formulation of the load and resistance functions, S and R, and deals with different sources of uncertainties through the use of safety factors.

7.6.1.2 Application of recognized material codes

When determining the structural integrity of elements of a WTGS, national or international design codes for the relevant material may be employed. Special care shall be taken when partial safety factors from national or international design codes are used together with partial safety factors from this standard. It shall be ensured that the resulting safety level is not less than the intended safety level in this standard.

Different codes subdivide the partial safety factors for materials, γ_m, into several material factors accounting for separate types of uncertainty, e.g. inherent variability of the material strength, extent of production control, or production method. The material factors given in this standard correspond to the so-called "general partial safety factors for materials" accounting for the inherent variability of the strength parameters. If the code gives partial safety factors or uses reduction factors on the characteristic values to account for other uncertainties, these shall also be taken into account.

Individual codes may choose different factorisations of partial safety factors on the load and the material parts of the design verification. The division of factors intended here is the one defined in ISO 2394. If the division of factors in the code of choice deviates from that of ISO 2394, the necessary adjustments in the code of choice shall be taken into account in the verification according to this standard.

7.6.2 Ultimate strength analysis

The resistance R generally corresponds with the maximum allowable design values of material resistance, hence $R(f_d) = f_d$, whilst the function S for ultimate strength analysis is usually defined as the highest value of the structural response in terms of stress. For multiple simultaneous loads the equation then becomes:

$$S\left(\gamma_{f1}F_{k1}, \cdots, \gamma_{fn}F_{kn}\right) \leq \frac{1}{\gamma_m \cdot \gamma_n} \cdot f_k \tag{24}$$

7.6.2.1 Partial safety factors for loads

Where the loads from various sources can be evaluated separately, the load factors shall have the values specified in table 3 as a minimum.

Table 3 - Partial safety factors for loads γ_f

Source of loading	Unfavourable loads			Favourable loads
	Type of design situation (see table 2)			All design situations
	Normal and extreme	Abnormal	Transport and erection	

Aerodynamic	1,35	1,1	1,5	0,9
Operational	1,35	1,1	1,5	0,9
Gravity	1,1/1,35*)	1,1	1,25	0,9
Other inertia	1,25	1,1	1,3	0,9

*) in the event of the masses not being determined by weighing.

In many cases, especially where varying loads result in dynamic load effects, the loads from various sources cannot be evaluated separately. In these cases, the partial safety factors for loads, γ_f, shall be taken as the highest of the partial safety factors for loads in table 3 for the relevant design situation.

Alternatively the computation of stresses and stress resultants can be performed with the combined loading corresponding to representative or characteristic values. Systematic variation of uncertain parameters of the governing equations shall be made in such a way that the level of safety implicitly defined by the partial safety factors for loads in table 3 is maintained.

7.6.2.2 Partial safety factors for materials where recognized design codes are not available

The partial safety factors for materials shall be determined in relation to the adequacy of the available material properties test data. The value of the general partial safety factors for materials accounting for the inherent variability of the strength parameter shall be not less than 1,1 when applied to characteristic material properties of 95 % survival probability, *p,* with 95 % confidence limit. If the characteristic material properties are derived for other survival probabilities, *p*, (but with 95 % confidence limit), and/or higher coefficients of variation, δ, the relevant general factor shall be taken from table 4. To derive the global partial safety factors for materials from this general factor it is necessary to account for scale effects, tolerances degradation due to external actions, i.e., ultraviolet radiation, humidity and defects that would not normally be detected.

Table 4 - General partial safety factors for materials for inherent variability

p %	δ =10 %	δ = 15 %	δ = 20 %	δ = 25 %	δ =30 %
99 %	1,02	1,05	1,07	1,12	1,17
98 %	1,06	1,09	1,13	1,20	1,27
95 %	1,10	1,16	1,22	1,32	1,43
90 %	1,14	1,22	1,32	1,45	1,60
80 %	1,19	1,30	1,44	1,62	1,82

Partial safety factors for consequences of failure:

Components class 1: γ_n = 1,0

Components class 2: γ_n = 1,0.

7.6.2.3 Partial safety factors for materials for where recognized design codes are available

The combined partial safety factors for loads, materials and the consequences of failure, γ_f, γ_m, and γ_n, shall be not less than those specified in 7.6.2.1, **Error! Unknown switch argument.** and 7.6.2.2, 7.6.2.2.

Where the survival probability, p, and the coefficient, δ, are not specified for the material, values p = 95 % and δ = 10 % can be assumed.

7.6.3 Fatigue failure

Fatigue damage shall be estimated using an appropriate fatigue damage calculation. For example, in the case of Miner's rule, the limit state is reached when the accumulated damage exceeds 1. So the accumulated damage within the lifetime of a turbine shall be less than or equal to 1:

$$\text{Damage} = \sum_i \frac{n_i}{N(\gamma_m \gamma_n \gamma_f s_i)} \leq 1{,}0 \tag{25}$$

where

- n_i is the counted number of fatigue cycles in bin i of the characteristic load spectrum, including all relevant load cases;
- s_i is the stress (or strain) level associated with the counted cycles in bin i, including the effects of both mean and cyclic range;
- $N(.)$ is the number of cycles to failure as a function of the stress (or strain) indicated by the argument (i.e. the characteristic S-N curve); and
- $\gamma_{(.)}$ is the appropriate material, consequences of failure, and partial safety factors for loads.

7.6.3.1 Partial safety factor for loads

The partial safety factor for loads factor, γ_f, shall be 1,0 for all normal and abnormal design situations.

7.6.3.2 Partial safety factors for materials where recognized codes are not available

The partial safety factor for materials, γ_m, shall be 1,1 provided that the S-N curve is based on not less than 95 % survival probabilities with 95 % confidence limits and a coefficient of variation of 10 %. If the characteristic material properties are derived for other survival probabilities, p, and/or other coefficients of variation, δ, the relevant general safety factor for materials shall be taken from Table 4. The fatigue strengths shall be derived from a statistically significant number of tests and the derivation of characteristic values shall account for scale effects, tolerances, degradation due to external actions, such as ultraviolet radiation, and defects which would not normally be detected.

Partial safety factors for consequences of failure

Components class 1: γ_n = 1,0

Components class 2: γ_n = 1,15.

7.6.3.3 Partial material factors where recognized design codes are available

The combined partial safety factors for loads, materials and consequences of failure shall not be less than those specified in 7.6.3.1, **Error! Unknown switch argument.** and 7.6.3.2, 7.6.3.2.

Where the survival probability, p, and the coefficient, δ, are not specified for the material property, values p = 95 % and δ = 10 % can be assumed.

7.6.4 Stability

No kink or buckling may occur in a component under characteristic load. Under design load, only the load-carrying parts of “non fail-safe” components shall not kink or buckle. For all other components elastic buckling may occur under this load.

A minimum value for the partial safety factor for loads, γ_f, shall be chosen in accordance with 7.6.3.1, to deal with uncertainties in extreme loads.

7.6.5 Critical deflection analysis

It shall be verified that no deflections affecting WTGS safety occur in the design conditions detailed in table 2. One of the most important considerations is to verify that no mechanical interference between blade and tower can occur.

The maximum elastic deflection in the unfavourable direction shall be determined for the load cases detailed in table 2 and multiplied by the combined partial safety factor for loads, material and consequences of failure safety factors.

Partial safety factor for loads

The partial safety factors for loads, γ_f, shall be chosen from table 3.

Partial safety factor for materials

The partial safety factor for materials material, γ_m, shall be chosen according to 7.6.2. Particular attention shall be paid to geometrical uncertainties and the accuracy of the deflection calculation method.

Partial safety factor for consequences of failure

Components class 1: γ_n = 1,0

Components class 2: γ_n = 1,0.

The elastic deflection shall then be added to the undeflected position in the most unfavourable direction and the resulting position compared to the requirement for non-interference.

7.6.6 Special partial safety factors

Lower partial safety factors for loads may be used where the magnitudes of loads have been established by measurement or by analysis confirmed by measurement to a higher than normal degree of confidence. The values of all partial safety factors used shall be stated in the design documentation.

8 Control and protection system

8.1 General

WTGS operation and safety shall be governed by a control and protection system which meets the requirements of this clause.

Manual or automatic intervention shall not compromise the function of the protection system. Any device allowing manual intervention must be clearly visible and identifiable, by appropriate marking where necessary.

Settings of the control and protection system shall be protected against unauthorised interference.

Any single failure in the sensing or the activation parts of the control system shall not lead to a malfunction of the protection system.

8.2 Wind turbine control

The control system of a WTGS shall control the operation by active or passive means and keep the operating parameters within their normal limits. Where selection of control mode can be exercised, e.g. for maintenance, control in each mode shall override all other control, with the exception of the emergency stop button. Mode selection shall be governed by a selector which can be locked in each position corresponding with a single mode. When certain functions are controlled numerically, access codes shall be provided to appropriately select the function.

The control system may govern functions or parameters such as:

- power limitation;
- rotor speed;
- connection of the electrical load;
- start-up and shutdown procedures;
- shut down at loss of electrical network or electrical load;
- cable twist limits;
- alignment to the wind.

8.3 Wind turbine protection

The protection system shall be activated when, as a result of control system failure or of the effects of an internal or external failure or of a dangerous event, a WTGS is not kept within its normal operation limits. The protection system shall then maintain the WTGS in a safe condition. The activation levels for the protection system shall be set in such a way that design limits are not exceeded.

The protection system shall be activated in such cases as:

- overspeed;
- generator overload or fault;
- excessive vibration;
- failure to shut down following network loss, disconnection from the network or loss of load;
- abnormal cable twist (due to nacelle rotation by yawing).

The protection system shall be designed for fail-safe operation. The protection system shall in general be able to protect a WTGS from any single failure or fault in a power source or in any non-safe-life component within the protection system.

If two or more failures are interdependent or have a common cause, they shall be treated as a single failure.

All non-redundant components of the protection system shall be analyzed for ultimate strength and fatigue failure and ultimate loads and meet the requirements of 8.4, 8.4.

8.4 Functional requirements of the control and protection system

The protection system shall include one or more systems (mechanical, electrical or aerodynamic) capable of bringing the rotor to rest or to an idling state from any operating condition. At least one of these shall act on the low speed shaft or on the rotor of a WTGS. Means shall be provided for bringing the rotor to a complete stop from a hazardous idling state in any wind speed less that V_{e1}. Disengagement of any emergency stop button following its use shall require an appropriate action. Disengagement shall not result in restart, only permit restart.

Measures shall be taken to reduce the risk from dormant failures. Non-safe life components and systems shall fail to a safe condition or their condition shall be automatically monitored; in either case their failure shall result in a machine shutdown. Safe-life designed components shall be inspected at adequate intervals.

An emergency stop button, which will override the automatic control system and result in a machine shutdown, shall be provided at every major working place.

In cases of conflict the protection function shall overrule the control function.

The automatic restart of a wind turbine shall not be possible where the shutdown was initiated by an internal fault or trip which is critical to the turbine safety.

9 Mechanical systems

9.1 General

The “mechanical systems” of a WTGS may include

– elements of the drive train such as gearbox(es), shaft(s) and coupling(s)

– auxiliary items such as brake(s), blade pitch control(s), yaw drive(s).

Auxiliary items may be driven by electrical, hydraulic or pneumatic means.

9.2 Errors of fitting

Errors likely to be made when fitting or refitting certain parts which could be a source of risk shall be made impossible by the design of such parts or, failing this, by information given on the parts themselves and/or housings. The same information shall be given on the moving parts and/or their housings where the direction of movement must be known to avoid a risk. Any further information that may be necessary shall be given in the operators instruction and maintenance manuals.

Where a faulty connection can be a source of risk, incorrect connections shall be made impossible by the design or, failing this, precautions shall be taken to avoid faulty connection by information given on the pipes, hoses and/or connector blocks.

9.3 Hydraulic or pneumatic systems

Where auxiliary items are powered by hydraulic or pneumatic energy the systems must be so designed, constructed and equipped as to avoid all potential hazards associated with these types of energy. Means of isolating or discharging accumulated energy must be included in the design.

All pipes and/or hoses carrying hydraulic oil or compressed air and their attachments shall be designed to withstand or be protected from foreseen internal and external stresses.

Precautions shall be taken to minimize risk of injury arising as a consequence of rupture.

10 Electrical system

10.1 General

The "electrical system" of a (multiple) WTGS installation comprises all electrical equipment installed in each individual WTGS up to and including the WTGS terminals; in the following referred to as the "WTGS electrical system".

The power collection system is not covered in this standard.

10.2 General requirements for the WTGS electrical system

All electrical components and systems shall meet the requirements of IEC 60204-1.

The design of a WTGS electrical system shall ensure minimal hazards to people and livestock as well as minimal potential damage to the WTGS and external electrical system during operation and maintenance of the WTGS under all normal and extreme external conditions defined in 6, 6.

A WTGS electrical system, including all electrical equipment and components, shall comply with the relevant IEC Standards. Specifically the design of a WTGS electrical system shall comply with the requirements of IEC 60364. For WTGS which contain circuits supplied at nominal voltages greater than 1000 Vac or 1500 Vdc, the manufacturer shall state the design standard used. The design of the electrical system shall take into account the fluctuating nature of the power generation from wind turbines.

A WTGS electrical system shall comply with relevant IEC Standards on electromagnetic compatibility, including IEC 61000-3-2, -3-3, -4-2, -4-3, -4-4, -4-5.

10.3 Protective devices

A WTGS electrical system shall, in addition to the requirements of IEC 60364, include suitable devices that ensure protection against malfunctioning of both the WTGS and the external electrical system which may lead to an unsafe condition or state.

10.4 Disconnect devices

It shall be possible to disconnect a WTGS electrical system from all electrical sources of energy as required for maintenance or testing.

Semiconductor devices shall not be used alone as disconnect devices.

Where lighting or other electrical systems are necessary for safety during maintenance, auxiliary circuits shall be provided with their own disconnect devices, such that these circuits may remain energized while all other circuits are de-energized.

10.5 Earth system

The design of a WTGS shall include a local earth electrode system to meet the requirements of IEC 60364 (for the correct operation of the electrical installation) and IEC 61024-1 (for lightning protection). The range of soil conditions for which the earth electrode system is adequate shall be stated in the design documentation, together with recommendations should other soil conditions be encountered.

The choice and installation of the equipment of the earthing arrangement (earth electrodes, earthing conductors, main earthing terminals and bars) shall be made in accordance with IEC 60364-5-54.

Any electrical system operating above 1,000 Vac or 1,500 Vdc shall be able to be earthed for maintenance.

10.6 Lightning protection

The lightning protection of a WTGS shall be designed in accordance with IEC 61024-1. It is not necessary for protective measures to extend to all parts of the WTGS, provided safety is not compromised.

10.7 Electrical cables

Where there is a probability of rodents or other animals damaging cables, armoured cables or conduits shall be used. Underground cables shall be buried at a suitable depth so that they are not damaged by service vehicles or farm equipment. Underground cables shall, if not protected by a conduit or duct, be marked by cable covers or suitable marking tape.

10.8 Self-excitation

Any electrical system that by itself can self excite the WTGS shall be disconnected and remain safely disconnected in the event of loss of network power.

If a capacitor bank is connected in parallel with a network-connected WTGS (i.e. for power factor correction), a suitable switch is required to disconnect the capacitor bank whenever there is a loss of network power, to avoid self-excitation of the WTGS electric generator. Alternatively, if capacitors are fitted, it shall be sufficient to show that the capacitors cannot cause self-excitation.

10.9 Over-voltage protection

The over-voltage protection shall be designed in accordance with the requirements of IEC 61312-1.

The limits of the protection shall be designed so that any over-voltage transferred to the electrical equipment will not exceed the limits established by the equipment insulation levels.

10.10 Harmonics and power conditioning equipment

The power conditioning equipment, such as invertors, power electronic controllers, and static VAR compensators, shall be designed so that harmonic line currents and voltage waveform distortion do not interfere with electrical network protective relaying. Specifically, for network-connected WTGS the voltage harmonics generated by the WTGS shall be such that the overall voltage waveform distortion at the network connecting point will not exceed the acceptable upper limit for the electrical network.

11 Assessment of external conditions

11.1 General

WTGS are subjected to environmental and electrical conditions which may affect their loading, durability and operation. In addition to the environmental conditions account has to be taken of the soil properties at the site where the WTGS is located.

It shall be assessed that the environmental, electrical and soil properties are more benign than those assumed for the design of a WTGS. If the site conditions are more severe than those assumed, the engineering integrity shall be demonstrated.

All offshore sites shall require WTGS class S turbines.

11.2 Assessment of wind conditions

As a minimum requirement, the wind conditions at the site shall be assessed according to the basic parameters listed below in terms of which the WTGS classes are defined.

– reference wind speed: V_{ref}
– annual average wind speed: V_{ave}
– turbulence intensity at V_{hub} = 15 m/s: I_{15}

where I_{15} is the characteristic value of hub height turbulence intensity at a 10 min average wind speed of 15 m/s. The characteristic value is calculated by adding the measured standard deviation of the turbulence intensity to the measured or estimated mean value.

The wind conditions shall be assessed from monitoring measurements made at the site, long term records or from local codes or standards. Where appropriate, the site conditions shall be correlated with long term data from local meteorological stations.

The monitoring period shall be sufficient to obtain a minimum of six months of reliable data. Where seasonal variations contribute significantly to the wind conditions, the monitoring period shall include these effects.

The value I_{15} shall be determined using appropriate statistical techniques applied to measured data obtained at wind speeds greater than 10 m/s [5]). Where topographical or other local effects may influence the turbulence intensity then these effects shall be represented in the data.

The characteristics of the anemometer, sampling rate and averaging time used to obtain measured data can influence the assessment of turbulence intensity. These effects shall be considered when predicting the turbulence intensity from measured data.

For complex terrain the wind conditions shall be assessed from measurements made at the site. In addition, consideration shall be given to the effect of topography on the wind speed, wind profile, turbulence intensity and flow inclination at each turbine location.

Wake effects from neighbouring machines shall be considered for WTGS operating in wind farms.

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5) Note, for example, that when low frequency trends exist in wind speed data, caution should be exercised in evaluating turbulence intensity and other parameters.

11.3 Assessment of other environmental conditions

The following environmental conditions shall be assessed for comparison with the assumptions made for design of the WTGS:

- normal and extreme temperature ranges;
- icing;
- humidity;
- solar radiation;
- chemically active substances;
- earthquakes;
- salinity.

11.4 Assessment of electrical network conditions

The electrical conditions at the interconnection between a WTGS and the existing electrical network at a proposed site shall be assessed to ensure compatibility with the WTGS and where appropriate, any electrical equipment between the WTGS and the existing electrical network. These shall include but not be restricted to the following:

- normal supply voltage and range;
- normal supply frequency and range;
- voltage imbalance;
- symmetric and unsymmetric faults;
- number of electrical network outages;
- auto-reclosing cycles;
- short-circuit impedance at the wind turbine terminals;
- ambient harmonic voltage distortion.

11.5 Assessment of soil conditions

The soil properties at a proposed site shall be assessed by investigation and with reference to available local building codes.

12 Assembly, installation and erection

12.1 General

The manufacturer of a WTGS shall provide a manual clearly describing installation requirements for the WTGS equipment. The installation of a WTGS shall be performed by personnel trained or instructed in these activities.

The site of a WTGS facility shall be prepared, maintained, operated and managed so that work can be performed in a safe and efficient manner. This should include procedures to prevent unauthorised access where appropriate. The operator should identify and eliminate existing and potential hazards.

Checklists of planned activities shall be prepared and logs of completed work and results of that work should be kept.

When appropriate, installation personnel shall use approved eye, feet, hearing, and head protection. All personnel climbing towers, or working above ground or water level, should be trained in such work and shall use approved safety belts, safety climbing aids or other safety devices. When appropriate, a buoyancy aid should be used around water.

All equipment shall be kept in good repair and be suitable for the task for which it is intended. Cranes, hoists and lifting equipment, including all slings, hooks and other apparatus, shall be adequate for safe lifting.

Particular consideration should be given to installation of WTGS under unusual conditions, such as hail, lightning, high winds, earthquake, icing, etc.

In the case of a tower standing without a nacelle, appropriate means shall be taken to avoid critical wind speeds for vortex generated transverse vibrations. The critical wind speeds and precaution measures shall be included in the installation manual.

12.2 Planning

The assembly, erection and installation of WTGS and associated equipment shall be planned in order that the work is carried out safely and in accordance with local and national regulations. The planning shall include, where appropriate, consideration of the following:

– rules for safe execution of excavation work;
– detailed drawings and specifications of the work and inspection plan;
– rules for the proper handling of embedded items, such as foundations, bolts, anchors and reinforcement steel;
– rules for concrete composition, delivery, sampling, pouring, finishing and placement of conduits;
– safety rules for blasting;
– procedures for installation of tower and other anchors;
– procedures for quality assurance.

12.3 Installation conditions

During the installation of a WTGS the site shall be maintained in such a state that it does not present a safety risk.

12.4 Site access

Access to a site shall be safe and the following shall be taken into account:

– barriers and routes of travel;
– traffic;
– road surface;
– road width;
– clearance;
– access weight bearing capacity;
– movement of equipment at the site.

12.5 Environmental conditions

During installation, environmental limits specified by the manufacturer shall be observed. Items such as the following should be considered:

– wind speed;
– snow and ice;
– ambient temperature;
– blowing sand;
– lightning;
– visibility;
– rain.

12.6 Documentation

The manufacturer of a WTGS shall provide drawings, specifications and instructions for assembly procedures, installation and erection of the WTGS. The manufacturer shall provide details of all loads, weights, lifting points and special tools and procedures necessary for the handling and installation of the WTGS.

12.7 Receiving, handling and storage

Handling and transport of wind turbine generator equipment during installation shall be performed with equipment confirmed to be suitable to the task and in accordance with the manufacturer's recommended practice.

WTGS are often sited on hilly terrain. Therefore, heavy equipment shall be set down in such a manner that it cannot shift. A suitably-sized, level lay-down area is preferred for all handling and assembly operations. Where this cannot be provided, all heavy equipment shall be securely blocked in a stable position.

Where there is risk of movement and damage by the wind, blades, nacelles, other aerodynamic parts and light crates shall be secured with ropes and stakes, or ground anchors.

12.8 Foundation/anchor systems

Where specified by the manufacturer for safe installation or assembly, special tools, jigs and fixtures and other apparatus shall be used.

12.9 Assembly of WTGS

A WTGS shall be assembled according to the manufacturer's instructions. Inspection shall be carried out to confirm proper lubrication and pre-service conditioning of all components.

12.10 Erection of WTGS

A WTGS shall be erected by personnel trained and instructed in proper and safe erection practices.

No part of a WTGS electrical system shall be energized during erection unless it is necessary for the erection process. In this case, the energization of such equipment shall be carried out in accordance with a written procedure to be provided by the WTGS supplier.

All elements where motion (rotation or translation) may result in a potential hazard shall be secured from unintentional motion throughout the erection process.

12.11 Fasteners and attachments

Threaded fasteners and other attachment devices shall be installed according to the WTGS manufacturer's recommended torque and/or other instructions. Fasteners identified as critical shall be checked and procedures for confirming installation torque and other requirements shall be obtained and used.

In particular, inspection shall be carried out to confirm the following:

– proper assembly and connection of guys, cables, turn buckles, gin poles and other apparatus and devices;

– proper attachment of lifting devices required for safe erection.

12.12 Cranes, hoists and lifting equipment

Cranes, hoists and lifting equipment, including all hoisting slings, hooks and other apparatus required for safe erection, shall be adequate for safe lifting and final placement of the loads. Manufacturer's instructions and documentation with respect to erection and handling should provide information on expected loads and safe lifting points for components and/or assemblies. All hoisting equipment, slings and hooks shall be tested and certified for safe load.

13 Commissioning, operation and maintenance

13.1 General

The commissioning, operation, inspection, and maintenance procedures shall be planned with the safety of personnel in mind and specified in the WTGS manual.

The design shall incorporate provisions for safe access for inspection and maintenance of all components.

The requirements of 10, **Error! Unknown switch argument.** also cover electrical measurement equipment temporarily installed in the wind turbine for the purpose of measurements.

When appropriate, operation and maintenance personnel shall use approved eye, feet, hearing and head protection. All personnel climbing towers, or working above ground or water level, shall be trained in such work and shall use approved safety belt, safety climbing aids or other safety devices. When appropriate, a buoyancy aid should be used around water.

13.2 Commissioning

Commissioning shall be carried out in accordance with manufacturer's recommended instructions.

13.2.1 Energization

The manufacturer's instructions shall include a procedure for initial energization of the WTGS electrical system.

13.2.2 Commissioning tests

WTGS's shall be tested, after installation, to confirm proper, safe and functional operation of all devices, controls and apparatus and be tested in accordance with manufacturer's recommended procedures. Testing shall include, but not be limited to:

– safe start-up;
– safe shutdown;
– safe emergency shutdown;
– safe shutdown from overspeed or representative simulation thereof;
– function test of protection system.

13.2.3 Records

Proper records shall be kept describing testing, commissioning, control parameters and results.

13.2.4 Post commissioning activities

At the completion of installation, and following operation for the manufacturer recommended running in period, the specific actions that may be required by the manufacturer shall be completed.

These can include, but are not limited to preloading of fasteners, changing of lubrication fluids, checking other components for proper setting and operation and proper adjustment of control parameters.

The WTGS site should be refurbished to remove hazards and prevent erosion.

13.3 Operations

The operation of a WTGS shall be performed by personnel suitably trained or instructed in this activity.

The normal operation of a WTGS by the operating personnel shall be possible at ground level. A tagged, local, manual override on the automatic/remote control system shall be provided.

13.3.1 Operations manual

An operators instruction manual shall be supplied by the WTGS manufacturer and augmented with information on special local conditions at the time of commissioning as appropriate. The manual should include:

– system safe operating limits and descriptions;
– start and shut down procedures;
– an alarms action list;
– emergency procedures plan.

The manual shall be available to the operation and maintenance personnel and shall be written in a language that can be read and understood by the operator.

13.3.2 Operations and maintenance record

Operations and maintenance records shall be kept and should include the following:

– wind turbine identification;
– energy produced;
– operating hours;
– shutdown hours;
– date and time of fault reported;
– date and time of service or repair;
– nature of fault or service;
– action taken;
– parts replaced.

13.3.3 Unscheduled automatic shutdown

Following any unscheduled automatic shut down caused by a fault or malfunction, unless specified otherwise in the operations manual or instructions, the operator shall investigate the cause before a WTGS is restarted. All unscheduled automatic shut downs should be recorded.

External events detected as faults but not critical for the future safety of a WTGS, such as loss and reinstatement of the electrical load, may allow automatic return to normal operation after completion of the shut down cycle.

13.3.4 Diminished reliability

Action shall be taken to eliminate the root cause of any indication or warning of abnormality or diminished reliability.

13.3.5 Work procedures plan

A WTGS shall be operated according to written procedures. The plan shall embody safe working procedures and include the following:

- manufacturers operations manual;
- electrical systems operation;
- co-ordination of operation and maintenance;
- utility clearance procedures;
- tower climbing procedures;
- equipment handling procedures;
- activity during bad weather;
- communications procedures and emergency plans.

13.3.6 Emergency procedures plan

Probable emergency situations shall be identified and the required actions of the operating personnel prescribed.

Where there is a fire or apparent risk of structural damage to the wind turbine or its components, no one should approach the WTGS unless the risk is specifically evaluated.

In preparing the emergency procedures plan it shall be taken into account that the risk for structural damage may be increased by situations such as the following:

- overspeeding;
- icing conditions;
- lightning storms;
- earthquakes;
- broken or loose guy-wires;
- brake failure;
- rotor imbalance;
- loose fasteners;
- lubrication defects;
- sandstorms;
- fire, flooding;
- other component failures.

13.4 Inspection and maintenance

13.4.1 General

The inspection and maintenance of a WTGS shall be carried out by personnel suitably trained or instructed in this activity, at the intervals specified in and in compliance with the instructions in the WTGS maintenance manual.

Guards designed to protect personnel from accidental contact with moving components shall be fixed, unless frequent access is foreseen where they may be movable.

Guards shall:

- be of robust construction;
- not be easy to by-pass;

– where possible, enable essential maintenance work to be carried out without their dismantling.

Provisions shall be made in the design for use of diagnostic fault finding equipment.

13.4.2 Design requirements

In order to ensure safety of the inspection and maintenance personnel, the design shall incorporate:

– safe access paths and working places for inspection and routine maintenance;
– adequate means to protect personnel from accidental contact with rotating components or moving parts;
– provision for securing lifelines and safety belts or other approved protection devices when climbing or working above ground level;
– provisions for blocking rotation of the rotor and yawing mechanism or other mechanical motion during servicing as well as provisions for safe unblocking;
– warning signs for live-conductors;
– suitable devices for the discharge of accumulated electricity;
– suitable fire protection for the personnel;
– an alternative escape route from the nacelle.

Maintenance procedures shall require safety cover for personnel entering any enclosed working space, such as hub or blade interior, that ensures immediate awareness of their situation and provides for their rescue in the event of any emergency.

13.4.3 Maintenance manual

Each WTGS shall have a maintenance manual which at a minimum consists of the maintenance requirements and emergency procedures specified by the WTGS manufacturer. The manual should also provide for unscheduled maintenance.

The maintenance manual shall identify parts subject to wear and indicate criteria for replacement.

Subjects which should also be covered in the manual include:

– description of the subsystems of the WTGS and their operation;
– lubrication schedule prescribing frequency of lubrication and types of lubricants or any other special fluids;
– recommissioning procedure;
– maintenance inspection periods and procedures;
– prescribed maintenance interval;
– procedures for functional check of protection subsystems;
– complete wiring and interconnection diagram;
– guy cable inspection and retensioning schedules and bolt inspection and preloading schedules, including tension and torque loadings;
– diagnostic procedures and trouble-shooting guide;
– recommended spare parts list;
– set of field assembly and installation drawings;
– tooling list.

Annex A
(normative)

Design parameters for describing WTGS class S

For WTGS class S turbines, the following information shall be given in the design documentation:

Machine parameters:

Rated power		[kW]
Hub height operating wind speed range	V_{in} - V_{out}	[m/s]
Design life time		[y]

Wind conditions:

Characteristic turbulence intensity as a function of mean wind speed	
Annual average wind speed	[m/s]
Average inclined flow	[deg]
Wind speed distribution (Weibull, Rayleigh, measured, other)	
Wind profile model and parameters	
Turbulence model and parameters	
Hub height extreme wind speeds V_{e1} and V_{e50}	[m/s]
Extreme gust model and parameters for 1 and 50 year recurrence intervals	
Extreme direction change model and parameters for 1 and 50 year recurrence intervals	
Extreme coherent gust model and parameters	
Extreme coherent gust with direction change model and parameters	
Extreme wind shear model and parameters	

Electrical network conditions:

Normal supply voltage and range	[V]
Normal supply frequency and range	[Hz]
Voltage imbalance	[V]
Maximum duration of electrical power network outages	[days]
Number of electrical network outages	[1/year]
Auto-reclosing cycles (description)	
Behaviour during symmetric and unsymmetric external faults (description)	

Other environmental conditions (where taken into account):

Design conditions in case of offshore WTGS (water depth, wave conditions, etc.)	
Normal and extreme temperature ranges	[°C]
Relative humidity of the air	[%]
Air density	[kg/m^3]
Solar radiation	[W/m^2]
Rain, hail, snow and icing	
Chemically active substances	
Mechanically active particles	
Description of lightning protection system	

Earthquake model and parameters

Salinity [g/m^3]

Annex B
(normative)

Stochastic turbulence models

The following stochastic turbulence models may be used for design load calculations. They satisfy the requirements given in 3.3.1. The turbulent velocity fluctuations are assumed to be a random vector field whose components have zero-mean Gaussian statistics. The power spectral densities describing the components are given in terms of the Kaimal spectral and exponential coherency model or by the Von Karman isotropic model.

Kaimal spectral model

The component power spectral densities are given in non-dimensional form by the equation:

$$\frac{fS_k(f)}{\sigma_k^2} = \frac{4f\ L_k/V_{hub}}{\left(1+6f\ L_k/V_{hub}\right)^{5/3}} \tag{B-1}$$

where

- f is the frequency in Hertz,
- k is the index referring to the velocity component direction (i.e. 1 = longitudinal, 2 = lateral, and 3 = vertical);
- S_k is the single-sided velocity component spectrum;
- σ_k is the velocity component standard deviation (see equation B-2);
- L_k is the velocity component integral scale parameter.

and with

$$\sigma_k^2 = \int_0^\infty S_k(f)df \tag{B-2}$$

The turbulence spectral parameters are given in the following table.

Table B.1 - Turbulence spectral parameters for Kaimal model

	Velocity component index (k)		
	1	2	3
Standard deviation σ_k	σ_1	0,8 σ_1	0,5 σ_1
Integral scale, L_k	8,1 Λ_1	2,7 Λ_1	0,66 Λ_1

Where σ_1 and Λ_1 are the standard deviation and scale parameters of turbulence, respectively, specified in the standard.

Exponential coherency model

The following exponential coherency model may be used in conjunction with the Kaimal autospectrum model to account for the spatial correlation structure of the longitudinal velocity component:

$$Coh(r,f) = \exp\left[-8{,}8\left(\left(f\cdot r/V_{hub}\right)^2 + \left(0{,}12r/L_c\right)^2\right)^{0,5}\right] \tag{B-3}$$

where

Coh(r,f) is the coherency function defined by the complex magnitude of the cross-spectral density of the longitudinal wind velocity components at two spatially separated points divided by the autospectrum function;

r is the magnitude of the projection of the separation vector between the two points on to a plane normal to the average wind direction;

f is the frequency in Hertz;

$L_c = 3{,}5\Lambda_1$ is the coherency scale parameter.

Von Karman isotropic turbulence model

The longitudinal velocity component spectrum is given in this case by the non-dimensional equation:

$$\frac{f S_1(f)}{\sigma_1^2} = \frac{4 f L/V_{hub}}{\left(1 + 71\cdot\left(f L/V_{hub}\right)^2\right)^{5/6}} \tag{B-4}$$

where

f *is the frequency in Hertz;*

$L = 3{,}5\ \Lambda_1$ is the isotropic integral scale parameter;

σ_1 *is the longitudinal standard deviation at hub height.*

The lateral and vertical spectra are equal and given in non-dimensional form by:

$$\frac{f S_2(f)}{\sigma_2^2} = \frac{f S_3(f)}{\sigma_3^2} = 2 fL/V_{hub}\ .\ \frac{1 + 189\cdot\left(f L/V_{hub}\right)^2}{\left(1 + 71\cdot\left(f L/V_{hub}\right)^2\right)^{11/6}} \tag{B-5}$$

where

L *is the same isotropic scale parameter as used in (B-4);*

$\sigma_2 = \sigma_3 = \sigma_1$, are the wind speed standard deviation components.

The coherency is given by:

$$Coh(r,f) = \frac{2^{1/6}}{\Gamma(5/6)}\left(x^{5/6} K_{5/6}(x) - 0{,}5 x^{11/6} K_{1/6}(x)\right) \tag{B-6}$$

where

x *is 2π((f.r/Vhub)2 + (0,12r/L)2)0,5;*

r *is the separation between the fixed points;*

L *is the isotropic turbulence integral scale;*

Γ(.) *is the gamma function;*

K(.)(.) *is the fractional-order, modified Bessel function.*

Equation (B-6) can be approximated by the exponential model given in equation (B-3), with L_c replaced by the isotropic scale parameter *L*.

Annex C
(normative)

Deterministic turbulence description

If the wind turbine modes, and specifically the rotor modes of vibration, are sufficiently damped, the following deterministic model may be used for the turbulence in normal wind conditions. The damping sufficiency may be verified using a simple stochastic model for the rotationally sampled wind velocity. In this simple verification model, an independent, sequentially uncorrelated random increment with a standard deviation of 5 % of the mean is added to the mean wind speed for each blade at each time step in a dynamic simulation model of the wind turbine. Each blade is assumed to be fully immersed in its respective instantaneous velocity field. The time histories of the simulated blade response variables of tip deflection and root bending moment (flap- and edge-wise) are then analyzed. This analysis consists of determining the ratio of the higher harmonic amplitudes to the fundamental amplitude at the rotational frequency. If these ratios are all less than 1,5, then the following deterministic model can be used:

Longitudinal velocity component:

$$\begin{aligned} V_1(y,z,t) &= V(z) + A_1 \sin(2\pi\ f_1 t) \\ &+ A_2 y \sin\left(2\pi\left[f_2 t + 1/4 \sin(2\pi\ f_3 t)\right]\right) \\ &+ A_2 z \sin\left(2\pi\left[f_2 t + 1/4 \cos(2\pi\ f_3 t)\right]\right) \end{aligned} \qquad \text{(C-1)}$$

where (y,z) are the lateral and vertical co-ordinates of points on the swept surface of the wind turbine rotor with origin at the rotor centre.

Lateral velocity component:

$$V_2(t) = A_3 \sin\left(2\pi\left(f_4 t + 1/4 \sin(2\pi\ f_5 t)\right)\right) \qquad \text{(C-2)}$$

The lateral velocity component may be assumed to be uniform over the rotor swept area.

For the previous wind velocity model, the amplitude and frequency parameters are given by the following relations:

Amplitude parameters:

$A_1 = 2{,}0\ \sigma_1$

$A_2 = A_1 / D$

$A_3 = 0{,}8\ A_1$

Frequency parameters:

$f_1 = 0{,}0194\ V_{hub} / \Lambda_1$

$f_2 = 4{,}0\ f_1$

$f_3 = f_1/10{,}0$

$f_4 = 0{,}6\ f_1$

$f_5 = f_4/10{,}0$

where

σ_1 is the hub-height wind speed standard deviation;

Λ_1 is the turbulence scale parameter;

V_{hub} is the ten-minute average, hub-height wind speed;

D is the turbine rotor diameter.

Note, that the lateral and longitudinal velocity components together define the instantaneous hub-height wind speed and direction using the relationships:

$$V_{hub}(t) = \left(\left(V_1(0{,}0,t)\right)^2 + \left(V_2(t)\right)^2 \right)^{0{,}5}$$

$$\theta_{hub}(t) = \tan^{-1}\frac{V_2(t)}{V_1(0{,}0,t)} \qquad \text{(C-3)}$$

Annex D
(informative)

Bibliography

The following standards can be relevant in the design of wind turbines:

IEC 60034	Rotating electrical machines
IEC 60038: 1983,	IEC standard voltages
IEC 60146	Semiconductor converters
IEC 60173: 1964,	Colours of the cores of flexible cables and cords
IEC 60227	Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V
IEC 60245	Rubber insulated cables of rated voltages up to and including 450/750 V
IEC 60269	Low-voltage fuses
IEC 60287	Electric cables - Calculation of the continuous current rating (100% load factor)
IEC 60439	Low voltage switch gear and control gear assemblies
IEC 60446: 1989,	Identification of conductors by colours or numerals
IEC 60529: 1989,	Degrees of protection provided by enclosures (IP Code)
IEC 60617	Graphical symbols for diagrams
IEC 60755: 1983,	General requirements for residual current-operated protective devices
IEC 60898: 1995,	Electrical accessories - Circuit breakers for overcurrent protection for household and similar installations
ISO 4354: 1997,	Wind actions on structures
ISO 8930: 1993,	General principles on reliability for structures – List of equivalent terms
ISO 9001: 1994,	Quality systems - Model for quality assurance in design/development, production, installation and servicing
ISO 9002: 1994,	Quality systems - Model for quality assurance in production , production, installation and servicing
ISO 9003: 1994,	Quality systems - Model for quality assurance in final inspection and test